PRICE $5.00

POWER SUPPLY

INSTRUCTION MANUAL

kepco®

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INSTRUCTION MANUAL

MODULAR DC
POWER SUPPLY

TL.201464

MODEL KS 60-5 (M)

SERIAL NO. #-53207.....

The Kepco equipment described in this instruction manual is of proprietary design, covered by one or more of the following United States patents, or by patents pending:

2,992,379	3,092,757
2,992,386	3,112,439
3,028,538	3,128,423
3,056,905	3,131,344
3,088,053	

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The line regulation specification for voltage mode operation of these Power Supplies has been respecified from 0.01% to 0.005%. Line regulation - voltage mode - is the amount of output voltage change (at any voltage setting) occasioned by a line change from 105-125V AC.

This improvement is accomplished at no increase in the cost of the instrument.

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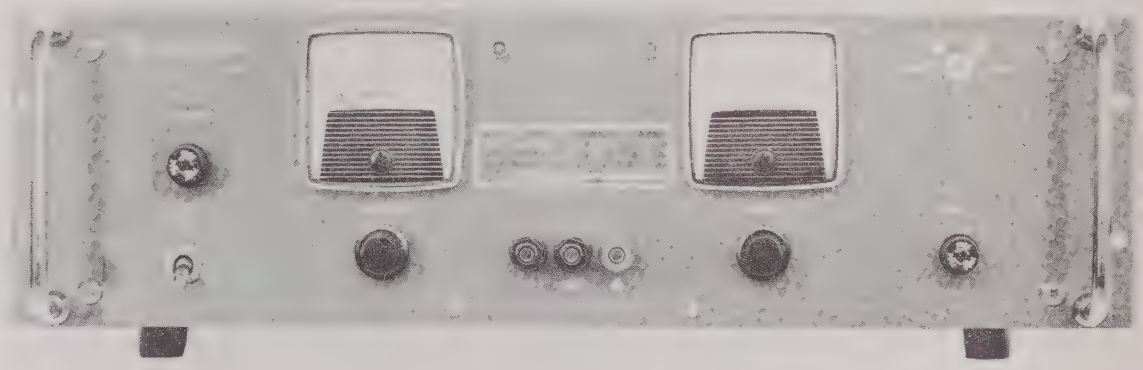


FIG. 1-1 KS SERIES POWER SUPPLY, FRONT VIEW (TYPICAL)

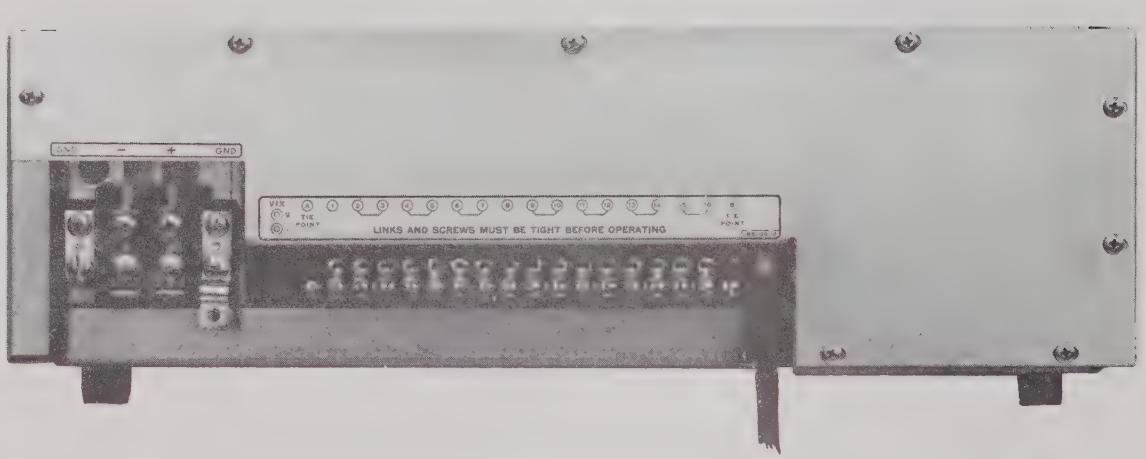


FIG. 1-2 KS SERIES POWER SUPPLY, REAR VIEW (TYPICAL)

1-1 SCOPE OF MANUAL

1-2 This instruction manual contains information for the installation, operation, and maintenance of the KEPCO Series KS regulated power supplies.

1-3 GENERAL DESCRIPTION (Refer to Fig's. 1-1 and 1-2)

1-4 The KEPCO KS Design Group consists of a series of precision regulated, highly efficient power supplies whose specifications and electrical characteristics are identical, except as noted in table 1-1. Phase controlled silicon controlled rectifiers in conjunction with a feedback regulating system provide the output power. High resolution controls in the voltage and current regulating modes are provided. Automatic crossover between the two operating modes is indicated by front panel lights. The rear barrier strip provides for the convenient access to the circuitry for the purpose of remote programming or system integration. Heavy duty rear output terminals for load connection are provided. Built-in forced air cooling with lateral circulation provides adequate ventilation for continuous operation at any output within the specified range.

1-5 The Power Supply chassis and case are constructed of plated cold rolled steel throughout. The front panel is heavy gauge aluminum finished in gray hammertone, unless otherwise specified, and equipped with chrome plated carrying handles.

1-6 The major part of the circuitry is on plug-in type printed circuit boards, and can be conveniently disassembled for maintenance purposes. All power transistors are installed into plug-in type assemblies, especially important for periodic maintenance checks.

1-7 SPECIFICATIONS, GENERAL

a) Input Requirements: 105 VAC to 125 VAC or 210 VAC to 250 VAC, 50 cps to 65 cps, single phase
For maximum input current see table 1-1.

b) Ambient Operating Temperature: -20°C to +50°C.

c) Storage Temperature: -40°C to +85°C.

d) Isolation Voltage: Maximum output voltage plus 500V DC between chassis and either output terminal.

1-8 SPECIFICATIONS, GENERAL PERFORMANCE

a) Controls: Continuously adjustable 10-turn voltage and current controls permit output settings from zero to the maximum voltage and current. Resolution: 0.05% of maximum output.

b) Programming: Special terminals provide for remote resistive programming of voltage or current at 100 ohms per volt. Programming terminals are also provided for programming by means of remotely located voltage or current signals.

c) Automatic Crossover: The automatic crossover circuit switches the operating mode of the power supply automatically from constant voltage to constant current or vice versa depending on the load relationship to the panel voltage and current adjustments. In the voltage regulation mode, the current control serves as a current limit adjustment while in current regulating mode, the voltage control serves as a voltage limiting adjustment.

d) VIX Indicators: The power supply's operating mode is indicated by a pair of front-panel signal lamps. One lamp is lighted during voltage regulated operation, the other during current regulated operation (internal current sensing only). Crossover from one mode to the other is signalled by the extinction of one lamp and the lighting of the other.

e) VIX Remote Signal: A pair of rear-panel pin jacks, labelled "V" and "I" provide external access to the VIX signal. Pin V is 8 volts positive with respect to pin I during voltage regulated operation. Pin I is 8 volts positive with respect to pin V during current regulated operation. Maximum loading: 10 K ohms; isolated from ground and the output terminals of the power supply. Crossover from one mode to the other is signalled by an abrupt polarity reversal.

f) Remote Error Sensing: Error sensing terminals enable specified voltage regulation to be maintained directly at the load by compensating for voltage drops up to 0.5 volts across each load supply lead.

g) Series/Parallel Operation: Automatic crossover capability permits series or parallel operation in either voltage or current regulating modes. Units operate automatically to share a load by means of their automatic crossover feature. Connections are also provided for operation in master/slave configuration.

h) Cooling: Lateral circulation by blowers insures efficient heat transfer; permits stacking of multiple units without overheating.

i) No Voltage Overshoot: No output voltage overshoot from turn-on, turn-off or power failure for output settings above 25% of maximum rated voltage. Below 25%, output overshoot is a function of load and is negligible for loads in excess of 10%.

1-9 SPECIFICATIONS, VOLTAGE REGULATION MODE

a) Regulation:

1) Line: Less than 0.01% output voltage change for 105-125V AC or 210-250V AC line variation, at any output voltage within the specified range.

2) Load: Less than 0.01% or 0.5 mv output voltage change, whichever is greater, for no load to full load change at any output voltage within the specified range.

b) Stability: Output voltage varies less than 0.01% or 3 mv, whichever is greater, over a period of 8 hours after warmup. Measured at constant line voltage, load and ambient temperature.

c) Temperature Coefficient: Output voltage changes less than 0.01% per °C.

d) Ripple: Less than 1 mv rms.

e) Recovery Time: 50 microseconds.

f) Output Impedance: Specified for each model within the load frequency range shown in table 1-1. Above 10 kc include the reactive impedance of the effective series inductance as indicated.

1-10 SPECIFICATIONS, CURRENT REGULATION MODE

a) Output Range:

1) Internal Sensing: Current regulation from less than 0.5% to 100% of the maximum specified current. Automatic crossover to voltage limiting provided.

2) External Sensing: Current regulation from 10 ma to 100% of the maximum rated current.

b) Compliance:

1) Internal Sensing: Voltage compliance range is zero to the voltage control setting. The setting is adjustable, zero to 100% of the rated voltage range.

2) External Sensing: Voltage compliance is zero to 100% of the maximum output voltage.

For any selected current value, the output voltage is automatically varied throughout the compliance range as required to regulate the output current through a variable load.

c) Regulation, Internal Sensing:

1) Line: Less than 0.01% or 1 ma, whichever is greater, output current change for 105-125V AC or 210-250V AC line variation at any output current within the specified range. For models rated at 10 amperes or less output current, the 1 ma regulation specification governs.

2) Load: Less than 0.01% or 1 ma, whichever is greater, output current change for the maximum change in load resistance within the rated compliance range. For models rated at 10 amperes or less output current, the 1 ma regulation specifications governs.

d) Regulation, External Sensing:

1) Line: For 105-125V AC or 210-250V AC line variations, output current changes less than 0.01% when the specified voltage sample is maintained across the external sensing resistor.

2) Load: For the maximum change in load resistance, within the rated compliance range, output current changes less than 0.01% when the specified voltage sample is maintained across the external sensing resistor.

The sensing resistor is chosen to produce a one volt drop at the maximum operating current. A separate control is used externally to provide high resolution current adjustability.

e) Stability: Output current varies less than 0.05% or 5 ma, whichever is greater, over a period of 8 hours after warmup. Measured at constant line voltage, load and ambient temperature.

f) Temperature Coefficient: Output current changes less than 0.05% per °C.

g) Ripple: Less than 0.1% of output current setting or 0.05% of maximum current rating, whichever is greater, rms.

1-11 SPECIFICATIONS, PHYSICAL

a) Meters: Model numbers in table 1-1 include 2 1/2", rectangular voltmeter and ammeter; 2% full scale accuracy. Unmetered units have the suffix "M" deleted from the model number.

b) Terminals and Controls:

1) On Front Panel: AC on-off switch, circuit breaker/fuse and two VIX mode lamps. 10-turn voltage control, 10-turn current control, reference circuit fuse, DC output and ground terminals (8 3/4" models have output terminals on the rear only).

2) On Rear of Chassis: Two VIX remote signal 0.08" pin jacks. Barrier strip connections for: remote error sensing, voltage and current programming by remote resistance and/or voltage, master-slave, parallel operation, external current sensing. DC output and ground terminals. Output terminals are isolated from the chassis, either positive or negative terminal may be grounded.

c) Dimensions: Standard ElA rack dimensions. Refer to Fig. 1-3.

d) Finish: Gray hammertone. (Special finishes to order).

1-12 ACCESSORIES

1-13 Accessory equipment for this power supply is available (but not supplied) to increase its range of applications.

a) VIX-1 Relay, translates the VIX remote signal, available at two connectors in the rear of the unit, into a heavy duty relay closure for external signal applications.

b) KP-10 PROGRAMMING PANEL, precision decade programming resistors for 6 digit voltage programming and 3 digit current programming.

c) FG-100, FUNCTION GENERATOR. Precision, slow speed, triangular wave generator for voltage programming of the power supply.

d) MP 1-3000, MOTORIZED PROGRAMMER. Provides a mechanical 10-Turn potentiometer sweep.

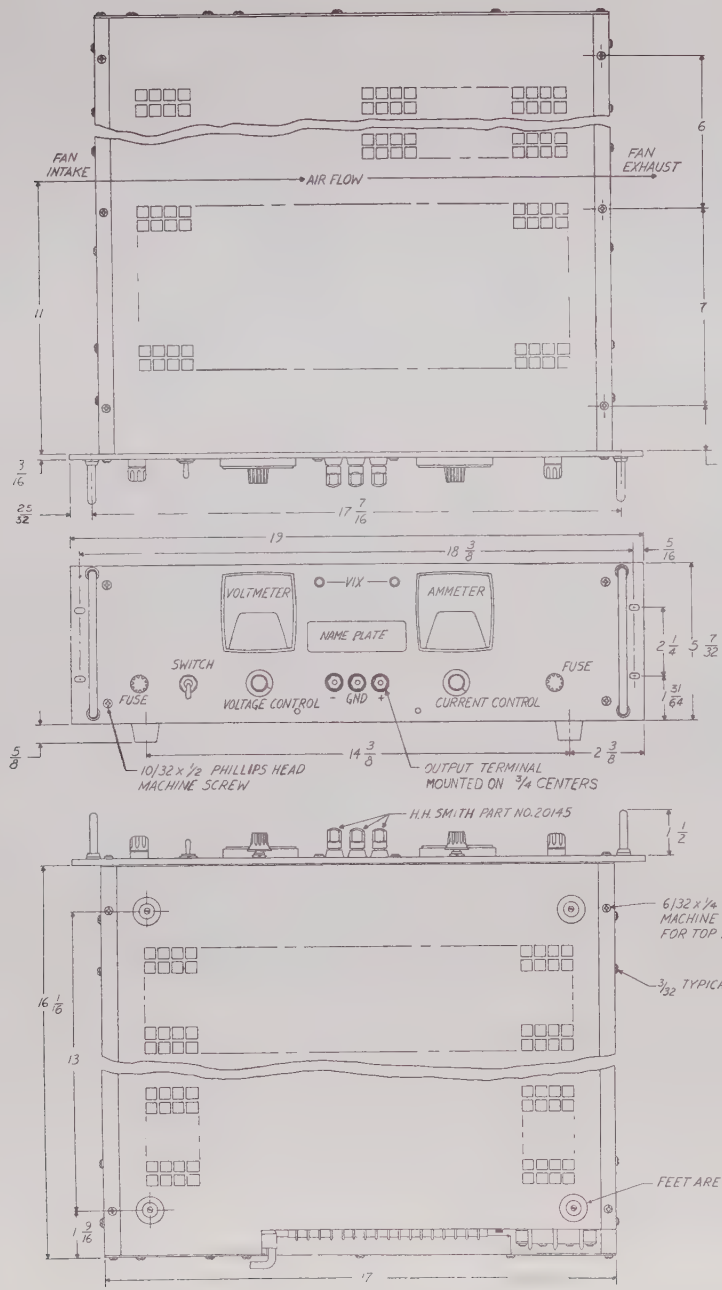
e) VIP-1*, OVERVOLTAGE/OVERCURRENT PROTECTOR, A 1% or 0.1V overvoltage will crow-bar the supply within 50 μsec.

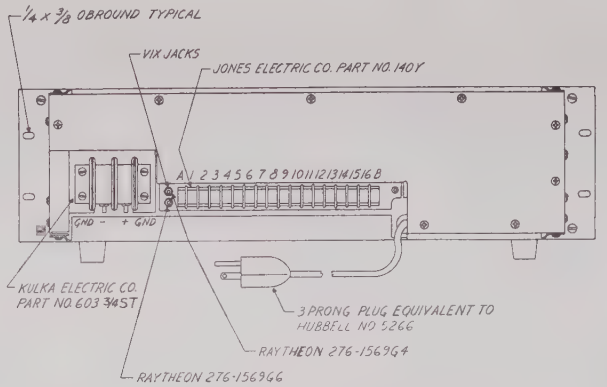
f) VIP-3*, OVER AND UNDER VOLTAGE
OVER AND UNDER CURRENT PROTECTOR
A 1% or 0.1V over or under voltage will crow-bar the supply within 50 μsec.

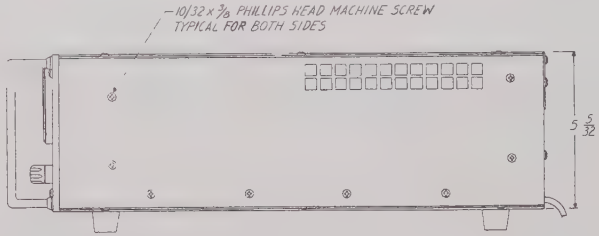
*For units up to 10 A input current only. For protective devices above 10A, inquire KEPCO Applications Engineering Department.

MODEL	DC OUTPUT RANGE		OUTPUT IMPEDANCE OHMS MAX.			MAX. INPUT AT 125 VAC	
	VOLTS	AMPS	DC to 100 CPS	100 CPS to 1 KC	1 KC to 100 KC + μh	AMPS	WATTS
KS 8-15M	0-8	0-15	0.05×10^{-3}	0.01	0.04 + 0.4	4.4	320
KS 8-25M	0-8	0-25	0.03×10^{-3}	0.01	0.04 + 0.4	8.5	565
KS 8-50M	0-8	0-50	0.016×10^{-3}	0.005	0.02 + 0.4	15.5	1000
KS 8-100M	0-8	0-100	0.008×10^{-3}	0.005	0.02 + 0.4	28	1950
KS 18-10M	0-18	0-10	0.18×10^{-3}	0.01	0.04 + 0.5	6.7	345
KS 18-15M	0-18	0-15	0.12×10^{-3}	0.01	0.04 + 0.5	8.0	510
KS 18-25M	0-18	0-25	0.07×10^{-3}	0.005	0.04 + 0.5	14.0	900
KS 18-50M	0-18	0-50	0.035×10^{-3}	0.005	0.02 + 0.2	26	1800
KS 36-5M	0-36	0-5	0.7×10^{-3}	0.02	0.1 + 1.0	4.8	290
KS 36-10M	0-36	0-10	0.4×10^{-3}	0.01	0.1 + 1.0	8.9	580
KS 36-15M	0-36	0-15	0.25×10^{-3}	0.01	0.1 + 0.6	12.2	860
KS 36-30M	0-36	0-30	0.1×10^{-3}	0.005	0.04 + 0.4	25	1600
KS 60-2M	0-60	0-2	3×10^{-3}	0.02	0.1 + 1.0	3.0	250
KS 60-5M	0-60	0-5	1×10^{-3}	0.02	0.1 + 1.0	7.0	500
KS 60-10M	0-60	0-10	0.6×10^{-3}	0.01	0.1 + 1.0	13.0	1000
KS 60-20M	0-60	0-20	0.3×10^{-3}	0.01	0.1 + 0.8	24	1700

TABLE 1-1 SPECIFICATIONS, KS SERIES POWER SUPPLIES




1/4 x 3/8 OBROUND TYPICAL
VIX JACKS
JONES ELECTRIC CO. PART NO. 140Y
A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 B
- GND
+ GND
KULKA ELECTRIC CO. PART NO. 603 3/4ST
3 PRONG PLUG EQUIVALENT TO HUBBELL NO. 5266
RAYTHEON 276-1569G4
RAYTHEON 276-1569G6



REAR OUTPUT TERMINAL FUNCTIONS

A
1 - CURRENT SENSING
2, 3 PROGRAM OF CURRENT BY VOLTAGE
4, 5 PROGRAM OF CURRENT BY RESISTANCE
6, 7 REMOTE LOAD SENSING, NEGATIVE
8 - GROUND
9, 10 REMOTE LOAD SENSING, POSITIVE
11, 12 PROGRAM OF VOLTAGE BY RESISTANCE
13, 14 PROGRAM OF VOLTAGE BY VOLTAGE
15, 16 PARALLEL OPERATIONS
B

NOTES:
1. THIS DRAWING USED FOR MODELS KS8-25M, KS18-15M, KS36-10M, KS60-5M
2. MATL, COVER NO. 16 COLD ROLLED STEEL, CADMIUM FINISH WITH A CHRONAK WASH, PANEL ALUM. ALLOY GRAY HAMMERTONE FINISH
3. FUSE DATA -

MODEL	FUSE F101	FUSE L02
KS8-25M	10 AMP	1 AMP
KS18-15M	10 AMP	1 AMP
KS36-10M	12 AMP	1 AMP
KS60-5M	10 AMP	1 AMP

4. REFER TO KEPCO CATALOG FOR DETAILED SPECIFICATIONS

FIG. 1-3 OUTLINE DRAWING

2-1 UNPACKING AND INSPECTION

2-2 This power supply has been completely tested and inspected at the factory prior to packing and is ready for installation and operation. No special precautions are necessary for unpacking the power supply. Inspect the instrument for obvious shipping damage before attempting to operate it. Perform an operational check as described in Par. 2-14. If there is any indication of damage, file a claim immediately with the transport service responsible.

2-3 TERMINALS AND CONTROLS

2-4 For the location of all terminations and controls, refer to Fig.s 2-2 and 2-3 as well as Tables 2-1 and 2-2. The nomenclature used will be followed throughout this manual.

2-5 A.C. INPUT REQUIREMENTS

2-6 This power supply is normally supplied for operation on a single phase, nominal 115 VAC line. For conversion to 230 VAC line operation, refer to Fig. 2-1. Refer to Table 1-1 for Input Current requirements.

2-7 GROUNDING

a) AC Ground. The power supply is equipped with a 3 wire safety line cord and polarized plug. The third (green) wire in the line cord is connected to the chassis and the case of the unit. If a two terminal receptacle in combination with an adaptor is used, it is imperative that the chassis of the power supply be returned to AC ground with a separate lead.

b) DC Ground. The D.C. output is isolated from the A.C. power line and from any direct connection to chassis or ground. The positive side of the output is connected to chassis through a capacitor in series with a resistor. The maximum voltage that can be supported between either output terminal and ground or chassis is 500V DC plus the maximum output voltage of the power supply. Either side of the output may be grounded. Convenient grounding terminals are provided at the front panel binding post (on units so equipped) or at the rear terminal strip.

2-8 LOAD CONNECTION

2-9 The load may be connected to the front panel binding posts (on units so equipped) or at the rear terminals. The regulation specifications as given in Section I are valid for rear terminal connections only. If optimum regulation directly at the load is essential, remote error sensing as described in Par. 3-16 must be applied.

2-10 COOLING

2-11 The power transistors and the rectifier assembly are maintained within the correct operating temperature by fan(s) circulating air laterally through the power supply. Side-panel openings and the top of the case must be kept clear from obstructions to insure proper circulation.

2-12 If the supply must be rack mounted or installed into confined space, care must be taken that the ambient temperature does not rise above the limit specified in Section I of this manual.

2-13 A protective thermostat located in pass transistor assembly A7, (Refer to Fig. 4-4) is interconnected with a power relay interlock to remove the line power in the event of excessive ambient temperature or a failure in the cooling system. If a thermal cut-out occurs, re-cycling of the power switch is required after proper thermal conditions have been restored.

2-14 OPERATIONAL CHECK

2-15 A simple operational check after unpacking and before permanently installing the power supply is advisable. The purpose of the test is to check the power supply for any damage resulting from shipment.
Note: Refer to Fig. 2-2 and Fig. 2-3 for location of front and rear terminations.

a) Connect power supply to 115 VAC line. Refer to Paragraph 2-5 for 230 V line operation and to Table 1-1 for input current requirements.

b) Turn "Current Control" fully clockwise. Rotate "Voltage Control" fully counter clockwise and then clockwise for one turn. For units without metering, connect a DC voltmeter across the rear output terminals. The range of the voltmeter must be sufficient to cover the maximum output voltage of the power supply.

c) Turn power "on". Slowly rotate the "Voltage Control" clockwise and observe the gradual increase of the output voltage. The "Voltage" VIX light should be on and the "Current" VIX light should be out. Turn power "off".

d) Connect a short circuit across the output terminals, consisting of a length of heavy copper wire. For unmetered models an ammeter with sufficient range to cover the maximum output current of the power supply may be connected in series with the short circuit.

e) Turn power "on". Rotate the "Current Control" slowly clockwise. A smooth increase in output current should be observed on the output current meter.* This completes the operational check of the power supply.

*The "Current" VIX light should be on, and the "Voltage" VIX light should be out.

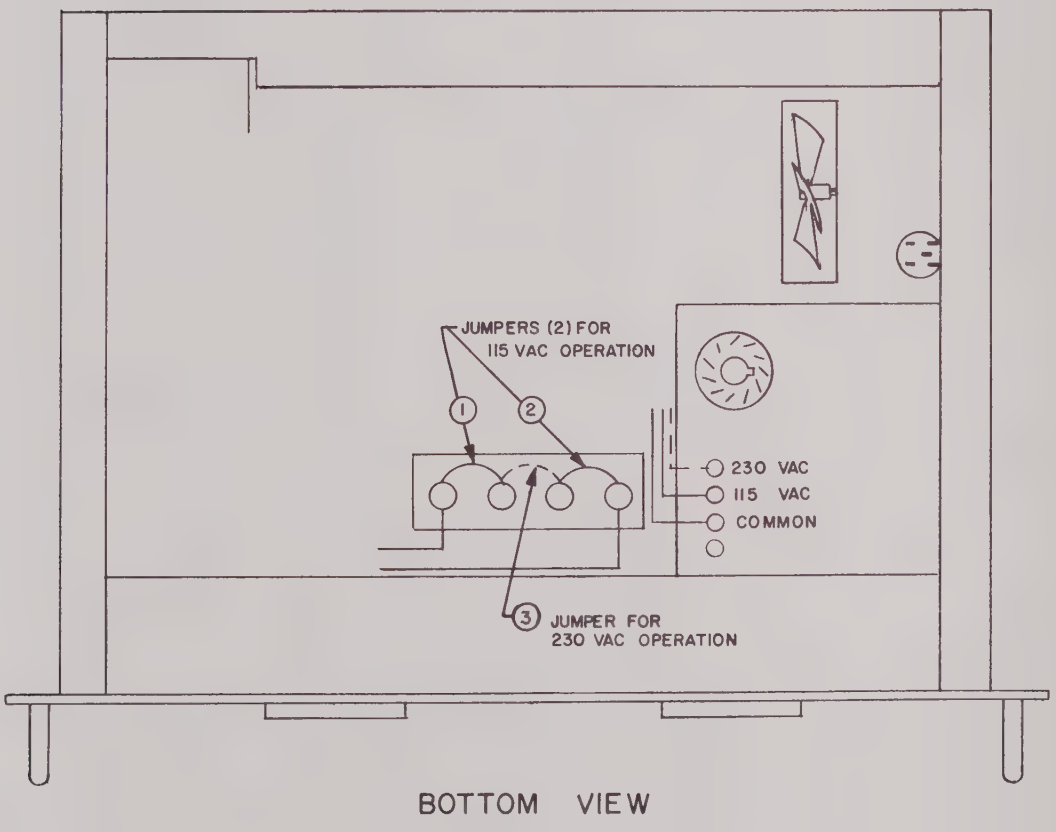


FIG. 2-1 TRANSFORMER CONNECTIONS FOR 115V AC AND 230V AC

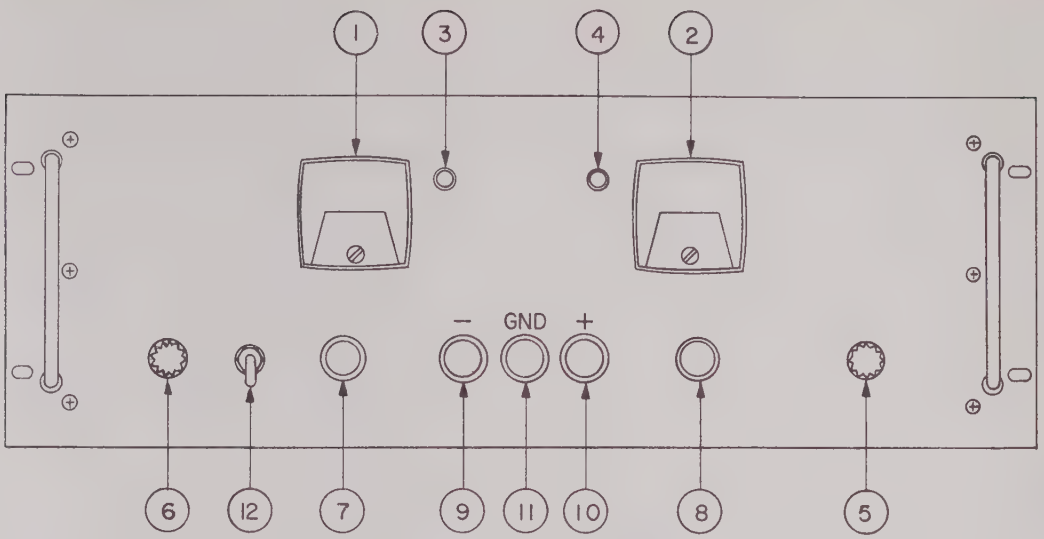
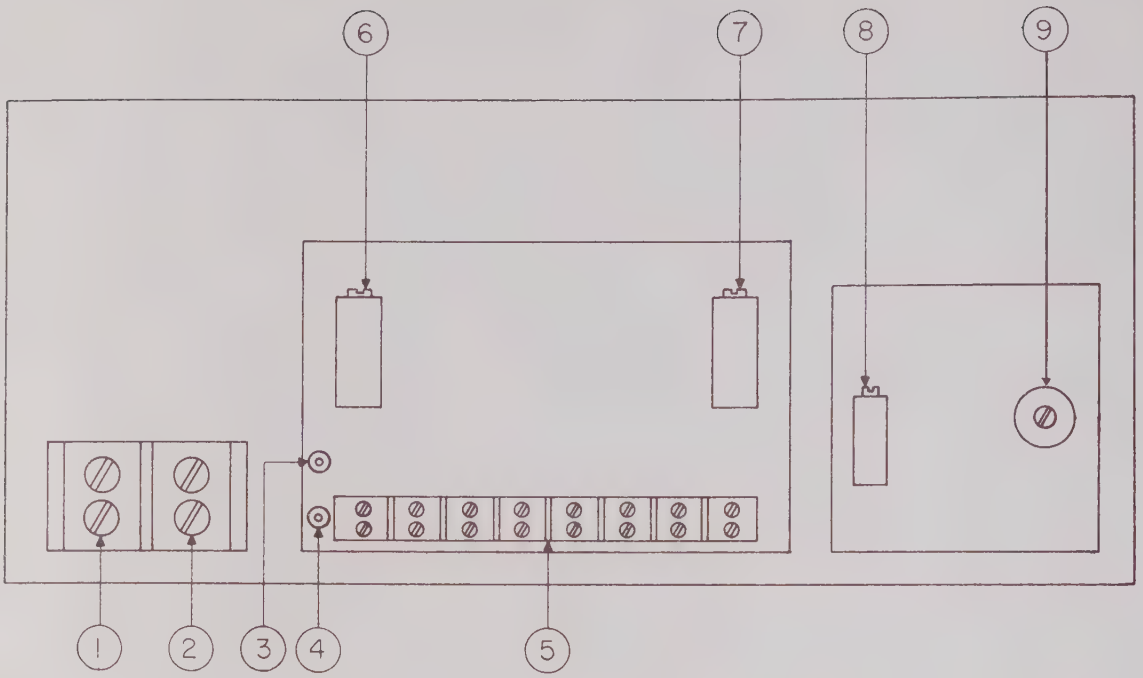


FIG. 2-2 TERMINATIONS, FRONT

TABLE 2-1 TERMINATIONS, FRONT

NO.	TERMINATION OR CONTROL	FUNCTION
1	VOLTMETER	INDICATES OUTPUT VOLTAGE
2	AMPERE METER	INDICATES OUTPUT CURRENT
3	VIX INDICATOR	DISPLAYS VOLTAGE OPERATING MODE
4	VIX INDICATOR	DISPLAYS CURRENT OPERATING MODE
5	FUSE	PROTECTS REFERENCE TRANSFORMER
6	FUSE	PROTECTS MAIN TRANSFORMER
7	VOLTAGE CONTROL	TEN TURN POTENTIOMETER, SETS OUTPUT VOLTAGE
8	CURRENT CONTROL	TEN TURN POTENTIOMETER, SETS OUTPUT CURRENT
9	OUTPUT TERMINAL(-)	MINUS TERMINAL, DC OUTPUT
10	OUTPUT TERMINAL (+)	PLUS TERMINAL, DC OUTPUT
11	OUTPUT TERMINAL (GND)	CHASSIS CONNECTION, RETURN TO AC GROUND
12	LINE SWITCH	CONNECTS UNIT TO AND FROM AC POWER LINE



REAR VIEW

FIG. 2-3 TERMINATIONS, REAR

TABLE 2-2 TERMINATIONS, REAR

NO	TERMINATION OR CONTROL	FUNCTION
1	OUTPUT TERMINAL (–)	MINUS TERMINAL, DC OUTPUT
2	OUTPUT TERMINAL (+)	PLUS TERMINAL, DC OUTPUT
3	VIX CONNECTOR	VIX SIGNAL OUTPUT (+ IN V MODE, – IN I MODE)
4	VIX CONNECTOR	VIX SIGNAL OUTPUT (– IN V MODE, + IN I MODE)
5	REAR BARRIER STRIP	16 CONNECTIONS TO INTERNAL CIRCUITRY (SEE SECT. 3)
6	R40, POTENTIOMETER	MAXIMUM CURRENT ADJUST (SEE SECT. 5)
7	R42 POTENTIOMETER	MAXIMUM VOLTAGE ADJUST (SEE SECT. 5)
8	R311, POTENTIOMETER	MAXIMUM PASS VOLTAGE ADJUST (SEE SECT. 5)
9	R322, POTENTIOMETER	MAXIMUM LINE SYNC. ADJUST (SEE SECT. 5)

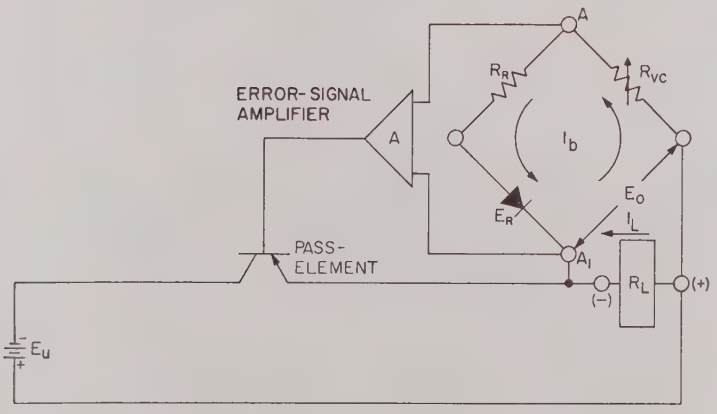
3-1 REMOTE PROGRAMMING OF KEPCO POWER SUPPLIES

3-2 General: In the Kepco Series "KS" Power Supplies, two comparison bridge circuits are used, each of which permit full range programming by resistance, voltage, current or conductance. The versatility of these circuits are so great that only the more common modes of operation can be described in this manual. For a more thorough coverage of power supply applications the "Kepco Power Supply Handbook", available from the Kepco Publication Department, is recommended.

In order to familiarize the user of this equipment with the power supply terminology used in this manual, and with the various modes of operations described in the following pages, the basic relationships governing the Kepco Bridge regulator should be clearly understood and kept in mind.

The bridge consists of four arms with the error amplifier connected to the "null" points (A, A_1). (See Fig. 3-1) The error amplifier, the power-source and the pass element constitute an inverting power amplifier which tends to regulate in such a way that equations (1), (2), and (3) are always valid. With these three basic equations in mind, the implications of the circuit variations given in the following paragraphs should become evident.

FIG. 3-1 KEPCO COMPARISON BRIDGE (SIMPLIFIED)



E_u = Unregulated Source
I_L = Load Current
I_b = Bridge Current
E_o = Output Voltage
E_r = Reference Voltage
R_L = Load Resistance
R_{VC} = Voltage Control Resistance
R_r = Reference - Resistance
A = Open Loop Gain Of Error Signal Ampl.

At balance: $E_{AA'} = 0$

(1) $\frac{E_r}{R_r} = \frac{E_o}{R_{VC}}$ (2) $I_b = \frac{E_r}{R_r}$ (3) $E_o = I_b R_{VC}$.

3-3 ADJUSTMENTS FOR EXACT PROGRAMMING RATIO

3-4 Definition. The setting of the "Voltage Control" on the front-panel adjusts the output voltage at a fixed, resistance to voltage ratio, which is determined by the bridge-current (I_b) flowing through the voltage control potentiometer (R_{vc}). Referring to our defining equations in Paragraph 3-2, and combining equations (1) and (2), we have: $E_o = I_b R_{vc}$ (equation 3). If therefore the bridge current is equal to 10 ma (as in all KS power supplies) we need, by Ohm's Law, 100 Ohms of control resistance (R_{vc}) for every volt of output: 10 ma (100 Ohms)= 1 volt. The ratio of the control resistance to the output voltage R_{vc}/E_o, which in the present case is established as 100 Ohm/volt, is termed the "Control Ratio" of the power supply.

3-5 Deviations. To compensate for inherent component tolerances, the control ratio in all KEPCO KS power supplies is adjusted slightly smaller than 100 ohm/volt. Also, a small error is introduced by the minute negative off-set voltage encountered at the output terminals when the voltage control is set to its maximum counterclockwise position. (Since $R_{vc} = 0$, in this case, we could expect, according to equation (3) that E_o would be zero). Both "inaccuracies" have been purposely designed into the power supply to facilitate precision adjustment of the programming ratio and are of no consequence in the ordinary operation of the power supply.

3-6 Adjustment. Resistance programming with precision decades or other highly accurate resistances require a control ratio accuracy comparable to the tolerances of the precision programming components. Two adjustments towards this end are necessary in the KEPCO KS Power Supply and described below.

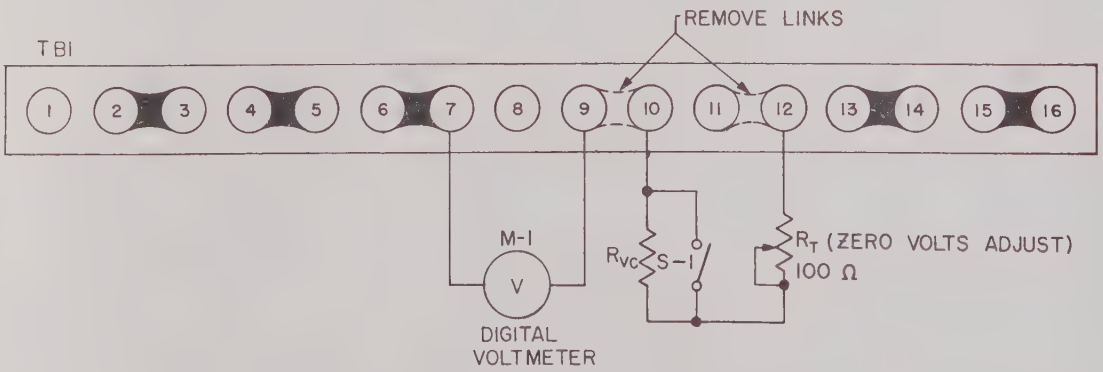


FIG. 3-2 CONNECTIONS FOR PRECISION PROGRAMMING RATIO ADJUSTMENT

3-7 PROCEDURE

a) Equipment Required:

1) Precision digital or differential voltmeter.

2) Precision resistor, 0.1% or better. (The value is not critical, but must be known precisely. For every 100 ohms, 1 volt output will appear across the voltmeter. This resistor will be externally connected as R_{VC}).

3) Adjustable, wire-wound resistor, 100 ohms. (A 15-turn wire-wound "TRIMPOT" potentiometer or its equivalent is recommended. This trimmer will be used as a zero adjustment).

4) Single Pole, single throw switch.

b) With line power removed from the power supply, remove links on the rear barrier strip between terminals (9) and (10) and between terminals (11) and (12).

c) Connect external components as shown in Fig. 3-2.

d) Turn line power "on". With S-1 open, and R_{VC} say 500 ohms, (known) approximately 5 volts output voltage will be read out on the digital voltmeter.

e) Adjust R42 Calibrate Control, for precisely 5.00 volts, (On printed circuit amplifier board, Fig. 2-3). Close S-1. Adjust R_t for precise Zero on the voltmeter.

f) Repeat (e) until no further readjustment on R42 or R_t is necessary.

CAUTION: Heavy duty output terminals for load connections are provided on the rear of the power supply. Do not connect the load to TB1, the barrier-strip on the printed circuit board. The terminals on this barrier-strip are for connections of control components and monitoring devices only and can not carry heavy current.

3-8 PROGRAMMING OUTPUT VOLTAGE WITH EXTERNAL RESISTANCE

3-9 General. The output voltage may be programmed or controlled over its entire range at the nominal 100 ohm/volt programming ratio of the KS power supplies. (If a precise ratio is desired, refer to Paragraph 3-3). In this mode of operation, the internal voltage control (R_{VC}) is disconnected and an external or remote voltage control resistance

is substituted. This resistance may take the form of a precision decade, fixed and step-switch controlled resistors or another potentiometer.

3-10 The relationships governing this type of programming are given by

$E_o = R_{vc} \frac{E_r}{R_r}$ (eq. 1) and Since $\frac{E_r}{R_r} = I_b$ (eq. 2) we can combine Eq. (2) and Eq. (1), to get $E_o = I_b R_{vc}$ (Eq. 3). Since I_b is (a nominal) 10 ma, 100 ohms, control resistance must be provided for each volt of output. This corresponds to a programming ratio of 100 ohm/volt.

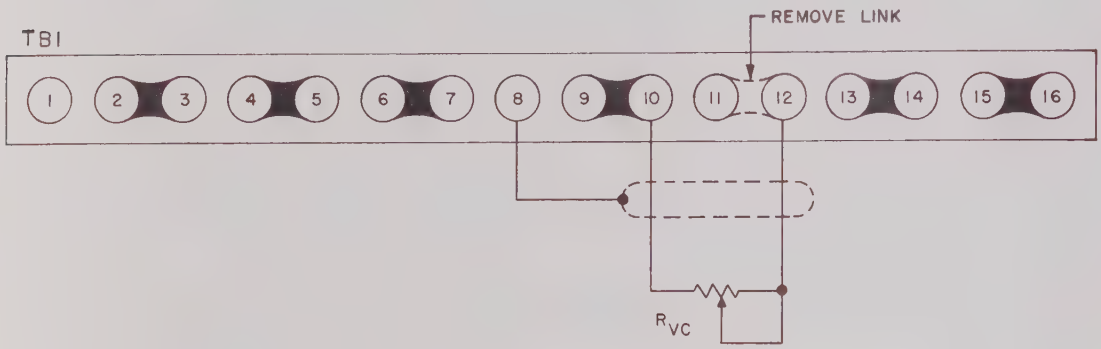


FIG. 3-3 CONNECTIONS FOR RESISTANCE PROGRAMMING

3-11 PROCEDURE

a) Remove link between terminals (11) and (12) at the rear barrier strip.

b) Using a shielded, twisted pair of wires, connect the external control resistance to terminals (10) and (12). Connect the shield to terminal (8).

NOTE: a) All resistors, used for external programming, must be high quality, wire wound units with a temperature coefficient of at least 20 ppm. Step-switch devices must be of the "make before break" variety.

b) The quiescent d.c. current through the programming resistors is the bridge current, or 10 ma. However, when programming large voltage excursions an error current flows. The power stored in the output capacitors will try to discharge partially through the control resistance and large peak currents may result. Therefore, the power dissipation rating of the control resistance should be several times that of the actual power dissipated under quiescent d.c. conditions.

3-12 PROGRAMMING OUTPUT VOLTAGE WITH EXTERNAL VOLTAGE

3-13 The output voltage of the KEPCO KS Power Supply can be controlled by an external, variable voltage source which replaces the fixed, built-in reference source. This mode of operation is referred to as "Voltage Programming". It can be mathematically expressed by referring to basic equation (1):

$$\frac{E_r}{R_r} = \frac{E_o}{R_{vc}} . \quad \text{Solving for } E_o, \; E_o = E_r \frac{R_{vc}}{R_r} .$$

Denoting the variable programming source E_i and substituting for E_r we have:

$$E_o = -E_i \frac{R_{vc}}{R_r} \quad \text{(equation 4)}$$

Consequently, if E_i is varied in this expression and the ratio $\frac{R_{vc}}{R_r}$, which represents the closed loop gain of the system, is held constant, the output voltage E_o will vary linearily with E_i. Referring back to equation (4) we see that the expression is similar to the inverted amplifier equation for an operational amplifier. The voltage programmed power supply does in fact become a unipolar power amplifier with potentially very high power gain but with limited frequency response. (Refer to Fig. 3-4). The limited frequency response is largely due to the effect of the output capacitor C_o acting as a low-pass filter and preventing the output voltage (E_o) from varying rapidly. The range in which E_o can be varied is limited only by the maximum output voltage of the power supply and by the leakage current of the comparison amplifier. This leakage current is in the order of 10μA flowing opposite to I_b, the programming current. It is therefore desirable to select I_b sufficiently high, in order to keep the leakage current insignificant with respect to I_b. For critical applications, the leakage current can be compensated out. The "Kepco Power Supply Handbook" provides information towards this end.

3-14 A practical example to illustrate the method of voltage programming will be given below:

EXAMPLE: A Kepco KS 36-10 power supply is to be programmed over its full range from a variable, unipolar source, with a peak output voltage of 3 volts and capable of delivering 10 ma of stable current. The internal voltage control and therefore the programming ratio of 100 ohm/v are to be retained. The programming ratio of 100 ohm/volt pertains to the programming source as well. Consequently the coupling resistor (R_i) must be 300 ohms.

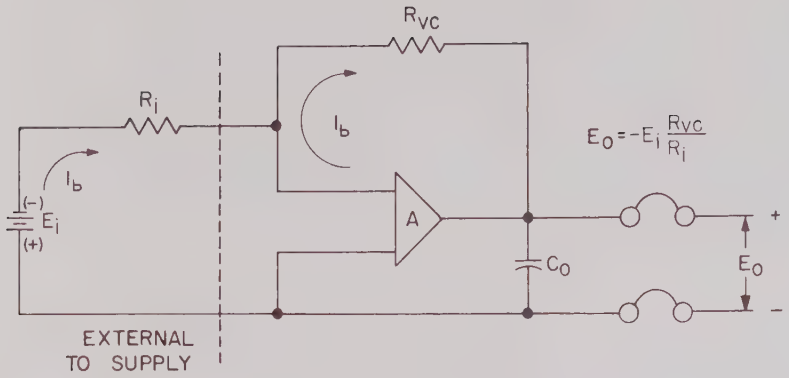


FIG. 3-4 VOLTAGE PROGRAMMING, OPERATIONAL NOTATION

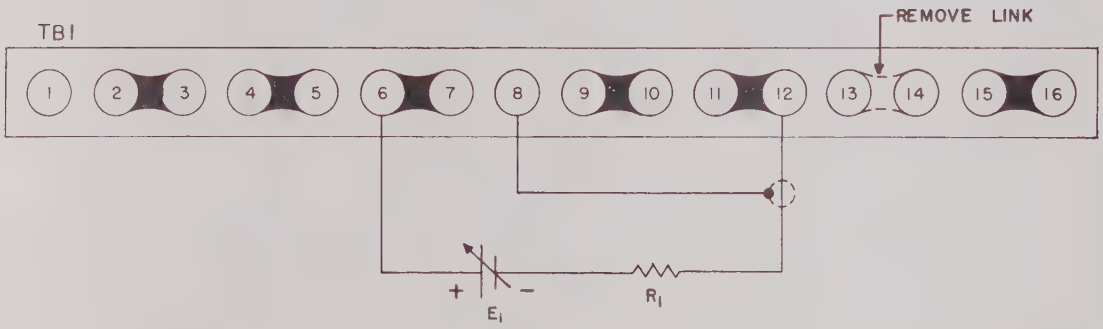


FIG. 3-5 CONNECTIONS FOR VOLTAGE PROGRAMMING

3-15 PROCEDURE (Refer to Fig. 3-5)

a) Remove link between terminals (13) and (14) on the rear barrier strip.

b) Connect selected components as shown, observe polarities.

c) Set the amplitude or voltage control of the programming source to the maximum selected programming voltage (3V).

d) Turn on the power supply to be programmed and the external programming source. Adjust the "Voltage Control" of the power supply to the selected maximum output voltage (36V).

e) The output voltage will now track variations in the programming voltage at the proportion established, (1:12).

3-16 REMOTE ERROR SENSING

3-17 GENERAL. The error sensing terminals (6) and (10), at the rear barrier strip are the input terminals to the regulating system of the power supply and are normally connected to the output terminals, providing specified regulation at these points. Voltage drops due to load current in the load connecting wires would degrade regulation directly at the load. Remote Error Sensing can be used to compensate for voltage drops up to 0.5 volts in each load wire, and provide specified regulation directly at the load.

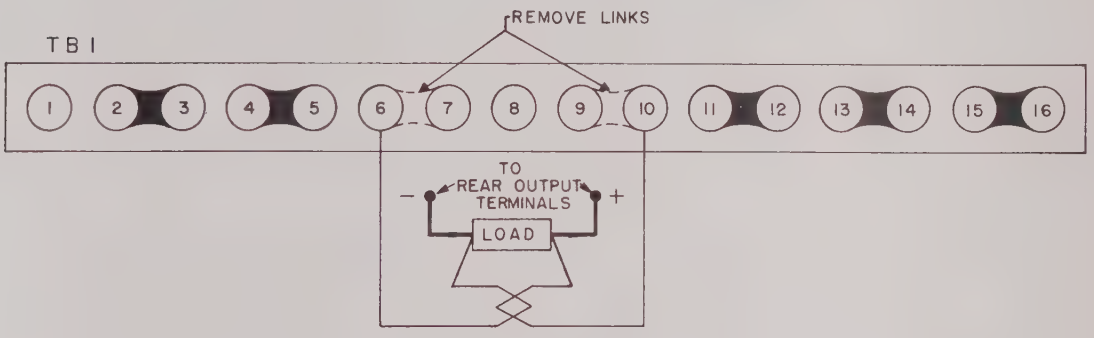


FIG. 3-6 CONNECTIONS FOR REMOTE ERROR SENSING

3-18 PROCEDURE (Refer to Fig. 3-6)

a) Remove links between terminals (6)-(7) and (9)-(10) on the rear barrier-strip. These links remove the error sensing from the output terminals and must be replaced when Remote Error Sensing is not being used.

b) Connect a twisted wire pair to the error sensing terminals (6) and (10). Observe polarity. Terminal (10), the positive error sensing terminal, must go to the positive side of the load, while terminal (6), the negative error sensing terminal must be connected to the negative side of the load. The error sensing wires carry the error signal and the bridge current but not the load current and may therefore be constructed from relatively small diameter wires, such as No. 20 AWG.

CAUTION: 1) OPEN LOAD LEAD. Before the power supply is turned on, make absolutely certain that the load wires are connected securely. If a loadwire should beccme disconnected while error sensing is used, the regulator will attempt to main-

tain load current flow through the sensing wires and damage to the power supply circuitry will result.

2) OPEN SENSING LEAD. Do not allow the power supply to operate with an open circuit between sensing terminals and their respective load terminals. This would degrade the regulation severely, cause the output voltage to rise, and increase the output ripple sharply. The output voltage rise in such a case is limited automatically to approximately 1.5 volts to protect the load.

3) Twisted loadwires of ample diameter are helpful in reducing transient recovery time. Stability problems when working into other than resistive loads can often be resolved by connecting a capacitor directly across the remote load.

3-19 PROGRAMMING OUTPUT CURRENT WITH EXTERNAL RESISTANCE

3-20 The output current of the KS power supply may be controlled externally by disconnecting the internal "Current Control" potentiometer and substituting an external control resistor. This external control may be fixed, stepped, or continuously variable, and it may be remotely located. If fixed resistors are used to step-control the current output, the switches used must be of the "Make Before Break" variety. (Shorting Contacts)

CAUTION: The absolute maximum of the output current is normally limited to 2% above the maximum rated output current of the power supply with its "Current Control" at maximun clockwise position. If an external control is used, it must be similarly adjusted with the external control at the maximum position. When returning to normal operation using the internal control it must again be returned to its previous adjustment. (Refer to Paragraph 5-12)

3-21 KEPCO KS power supplies generally use 0.5 volt sensing voltage and a 50 ohm "Current Control" potentiometer, resulting in a current programming ratio of 100 ohm/volt. The only exception in the KS series is the KS 60-2, which uses 1 volt of sensing and a 100 ohm control, retaining however the 100 ohm/volt programming ratio. Any external combination of resistors or any continuous control resistance, equal to 50 ohm (or 100 ohm in case of the KS 60-2) will program the output current of the KS supply through its entire range. An example of a step control programming set-up is given in the procedure below.

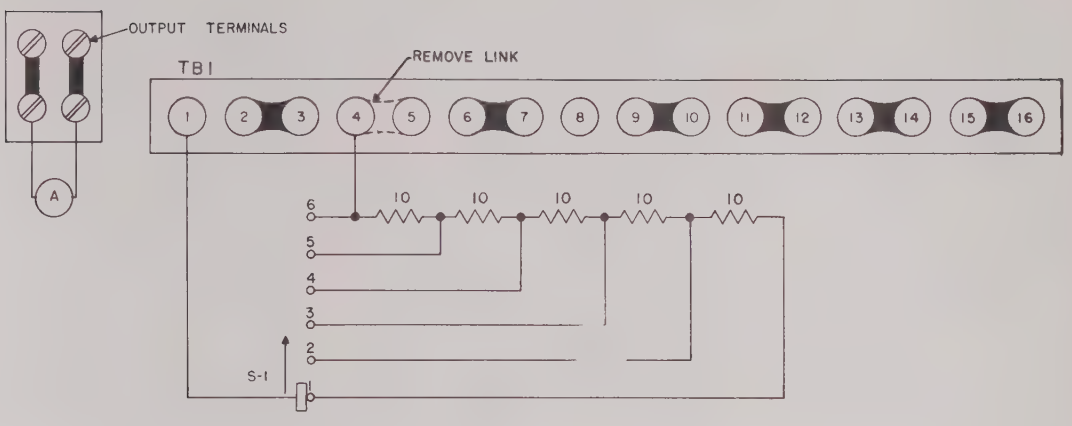


FIG. 3-7 CONNECTIONS FOR RESISTANCE PROGRAMMING (CURRENT MODE)

3-22 PROCEDURE

3-23 EXAMPLE: The output current of a KS 18-10 is to be programmed in steps of 2 Ampere up to the maximum output current of the unit.

a) Since we need 50 ohms total resistance for R_{cc}, five 10 ohm resistors are connected to a 6 position switch (with shorting contacts) as shown in Fig. 3-7.

b) Connect an ampere-meter as a short circuit across the output terminals of the power supply.

1) The range of the ampere meter must be sufficient to include the maximum output current of the unit.

2) The desired accuracy of the output current steps, will depend upon the accuracy of the meter.

3) The connecting leads to the meter should be short and sufficient in diameter to carry the maximum current.

c) Turn power supply "on". With S-1 in position as shown, adjust R40 (Refer to Fig. 2-3 for location) to the exact maximum output current (10A).

d) All successive positions will yield the proportional output current,

pos 1) = 10 A
pos 2) = 8 A
pos 3) = 6 A
pos 4) = 4 A
pos 5) = 2 A
pos 6) = 0 A

3-24 PROGRAMMING OUTPUT CURRENT WITH EXTERNAL VOLTAGE

3-25 The output current of the KS power supply can be voltage programmed in a manner similar to that described in Paragraph 3-12. The fixed reference supply (E_r and R_r) in the current bridge circuit is removed and replaced by a variable programming source E_i with coupling resistor R_{rc}. The output current will vary in accordance with the equation $I_o = \frac{E_i R_{cc}}{R_{rc} R_s}$, where R_s is the current sensing resistor and R_{cc} the Current Control. If the original programming ratio is to be maintained, the programming source must be capable of supplying 10 ma of stable current. The value of R_{rc}, the external coupling resistor is found by multiplying the maximum programming voltage (E_i) by the control ratio: $R_{rc} = E_i$ (100 Ohm/volt os sensing). R_{rc} should be variable to be able to adjust the output current to its maximum rated value. An example will be shown below to illustrate the application of this mode of operation.

3-26 EXAMPLE: A KS 8-15 is to be voltage programmed in the current mode from zero to full output current. The programming source is a unipolar, variable supply, capable of delivering at least 10 ma and with a maximum voltage of 25 volts.

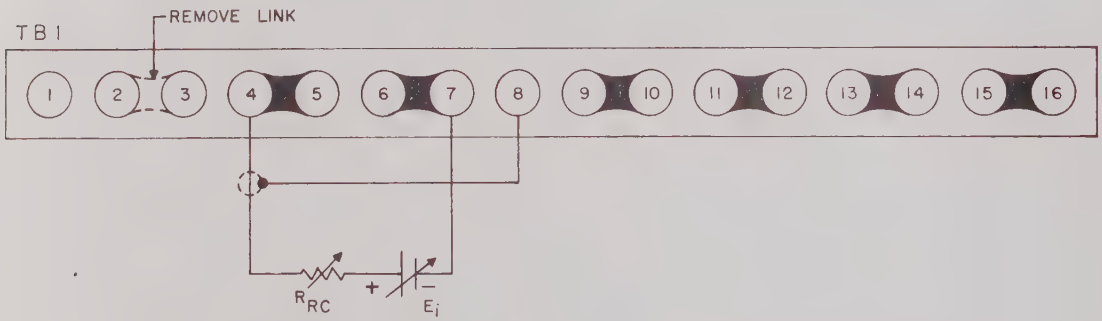


FIG. 3-8 CONNECTIONS FOR PROGRAMMING OUTPUT CURRENT WITH EXTERNAL VOLTAGE

3-27 PROCEDURE:

a) Select the external coupling resistor R_{rc}. Since the external programming source is capable of delivering 10 ma, the 100 ohm/v control ratio can be maintained. R_{rc} is found by multiplying the maximum amplitude of the programming source (E_i max.) by this ratio:

$$E_i \text{ max.} \left(\begin{matrix}\text{Programming} \\ \text{Ratio}\end{matrix}\right) = 25 \left(\frac{100 \text{ ohm}}{V_s}\right) = 2500 \text{ ohm}$$

We will split this resistor into a fixed 2000 ohm part and an adjustable 1 K ohm potentiometer.

b) Connect the programming set-up as shown in Fig. 3-8. Turn both, "Voltage Control" and "Current Control" on the front panel of the power supply fully clockwise.

c) Connect a short circuit, consisting of an accurate Ampere meter with short connecting lead of adequate diameter, able to carry the maximum output current of the power supply, across the output terminals.

d) Set the programming source to its maximum output voltage and R_{rc} to its maximum Resistance Value.

e) Turn power supply and programming source "on". With R_{rc} at its maximum resistance value, the output current as read on the external ammeter should be below its maximum rated value. Adjust R_{rc} in the direction of decreasing resistance until output current will reach its rated maximum value. The programming source will now vary the output proportionally.

3-28 OUTPUT CURRENT REGULATION USING EXTERNAL SENSING

3-29 External sensing for the purpose of superior regulation at low currents may be used with KS power supplies. In the internal "Current Regulation" Mode, an internal sensing resistor R_s is used to generate a voltage drop proportional to the load current flowing through it. This voltage drop as applied to the current comparison bridge, constitutes the output voltage for comparison purposes. This voltage drop across R_s changes with load-current, since I_L is made variable in the KS supplies. Optimum regulation however can only be achieved over a comparatively narrow range of V_s, the voltage across sensing resistor R_s, so that in a variable current supply a compromise in the selection of R_s must be made. If external sensing is used, R_s can be selected close to its optimum value and excellent regulation of small load current over a narrow range can be achieved.

3-30 In the external sensing mode, the voltage comparison bridge is being used to regulate current. The current bridge is inactive and consequently automatic cross-over does not take place and only the "Voltage" VIX indicator will be energized. The practical application of this mode of operation will best be shown by an example.

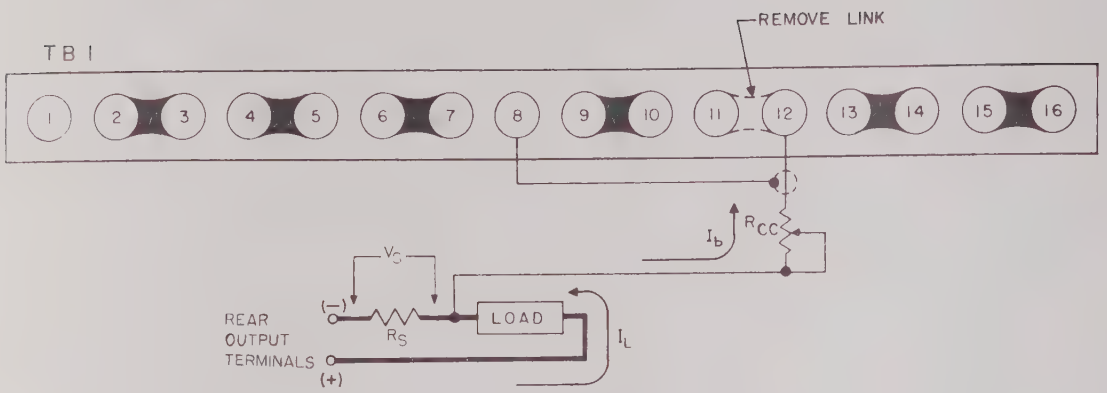


FIG. 3-9 CONNECTIONS FOR CURRENT REGULATION USING EXTERNAL SENSING

3-31 EXAMPLE:

a) A constant current of 110 ma is needed. The power supply available is a Kepco KS 8-100. Since the current required is out of this supplies' regulation range (0.5% - 100%), external sensing will be used.

b) A 1 volt sample voltage across R_S will be selected, requiring a coupling resistor R_C of 100 ohms, according to the established control ratio of the KS supply (100 ohm/volt).

c) R_S, the sensing resistor is calculated by Ohm's Law:

$$R_S = \frac{V_S}{I_O - I_b}, \quad R_S = \frac{1 \text{ volt}}{(0.11A - 0.01A)} = 10 \text{ ohm.}$$

The power dissipated in R_S, is $P_{diss} = 0.1$ watt. A 10 ohm, W.W., 1 W resistor with a T.C. of 20 ppm or better will be used.

d) Connect the selected components as shown in Fig. 3-9. If R_{CC} is made variable, the output current can be varied with it over an approximately 1:10 range. At 10 ma I_O however, the supply will lose control, because the control current which is in the order of 10 ma, will tend to cancel the load current through the sensing resistor, producing a large error signal at the comparison bridge.

CAUTION: When using external sensing, the load must be connected at all times, Since the power supply is operating with the voltage comparison bridge, opening the load wires would appear to the error amplifier as an infinite resistance load, and the maximum unregulated voltage will appear at the output.

3-32 SERIES OPERATION OF KS POWER SUPPLIES

3-33 KEPCO KS power supplies can be series connected for increased voltage output provided the specified limits on voltage to chassis are not exceeded. When series connected, the supplies should be protected by means of a semi-conductor diode across the output terminals of each supply. The peak-inverse voltage of these diodes must be at least as large as the output voltage of the supply to which they are connected. The continuous current rating of the protective diodes must be greater than the maximum output current of the inter-connected supplies.

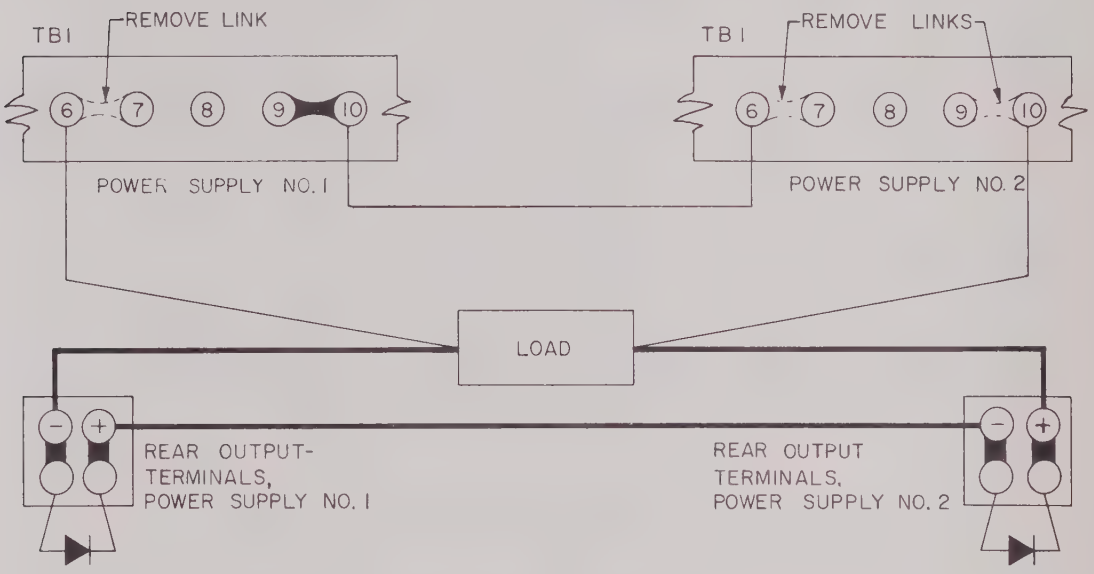


FIG. 3-10 CONNECTION FOR IN-SERIES OPERATION

3-34 PROCEDURE

a) Connect load to power supplies as shown in Fig. 3-10. Keep voltage drops in the load wires as low as possible by selecting the gauge as heavy as practicable.

b) Connect protective diodes across their respective output terminals.

c) Remove jumper-links as shown and connect error sensing leads. These leads carry negligible current and may be light gauge wire.

d) Turn both supplies on, and adjust voltage on either control as required.

3-35 PARALLEL OPERATION OF KS POWER SUPPLIES

For the purpose of obtaining higher load current, paralleling of KEPCO KS Power Supplies is possible. Several methods can be used, two of the most common ones are given below.

3-36 MASTER-SLAVE CONNECTION. In this method of paralleling, the pass-elements of both units are effectively combined and driven from a common control derived from the master supply amplifier. Up to three supplies can be operated in this manner, beyond this number, other methods must be used. (Refer to Paragraph 3-38)

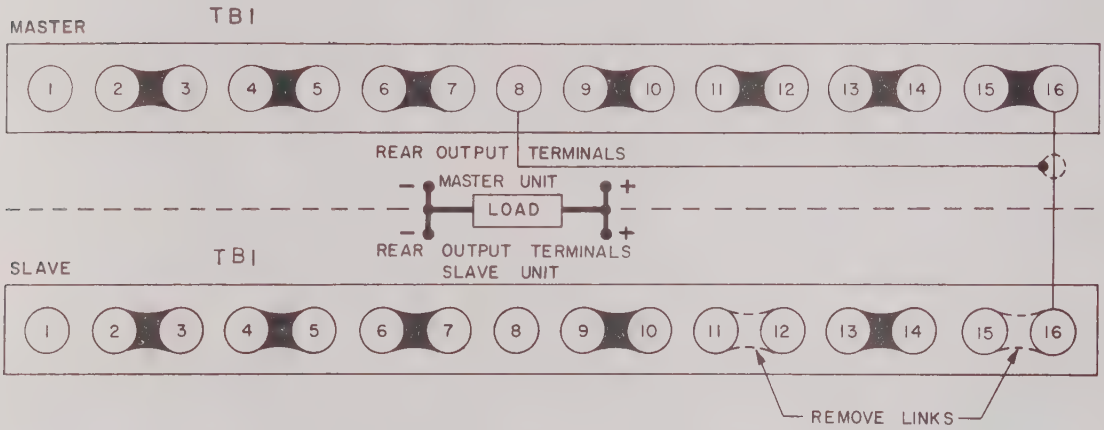


FIG. 3-11 SERIES OPERATION, MASTER-SLAVE CONNECTION

3-37 PROCEDURE (Refer to Fig. 3-11)

a) Remove jumper links between terminals (11)-(12) and (15)-(16) on the rear barrier strip of the slave unit. Join terminals (16) of both units with a shielded wire and connect the shield to terminal (8) on the master unit.

b) Connect load with equal length of wire from each power supply to insure optimum current sharing. (This becomes especially important when load currents close to the combined maximum current limits are required).

c) Connect remote error sensing, if required, from the error sensing terminals of the master unit to the load as described in Paragraph 3-17.

d) Connect power supplies to line simultaneously by means of a common power switch.

3-38 AUTOMATIC CROSS-OVER CONNECTION. This method does not involve any special interconnections, except for common A.C. powerline switching and connection of the load with an equal length of wire. Each supply is set to the desired output voltage with it's respective "Current Control" set to its maximum clockwise position. After turn-on, one of the supplies will be at a slightly higher output voltage than the rest, (Supply #1). It is this supply that will deliver all the current up to its own current limit. As the load is increased, the supply with the second highest output voltage will take over and deliver the additional current up to its "Current Control" setting, and so on, until all parallel supplies are sharing the load current. The "Current Controls" of all supplies can now be set to achieve approximately equal current sharing.

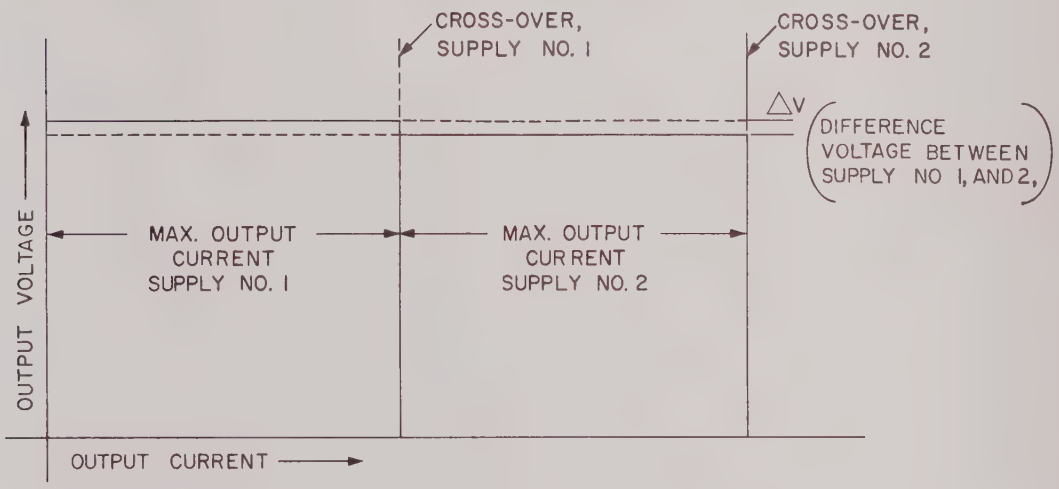

CROSS-OVER, SUPPLY NO. 1
CROSS-OVER, SUPPLY NO. 2
△V
DIFFERENCE VOLTAGE BETWEEN SUPPLY NO 1, AND 2,
MAX. OUTPUT CURRENT SUPPLY NO. 1
MAX. OUTPUT CURRENT SUPPLY NO. 2
OUTPUT VOLTAGE
OUTPUT CURRENT

FIG. 3-12 AUTOMATIC CROSS-OVER, KS POWER SUPPLIES

Fig. 3-12 shows in diagram form how power supplies operate in AUTOMATIC CROSSOVER mode. It will be obvious from the diagram that since the output voltages are never exactly equal, a "delta V" exists, which would, if an attempt were made to measure load regulation over the whole range, add to the "regulation delta V" and would result in erroneous readings. Load regulation therefore can be measured in the individual output current bands only.

NOTE: When paralleling KS power supplies, care should be exercised to avoid turning only one of the voltage controls close to zero. This precaution will prevent excessive currents in the control potentiometer as its limiting resistance is lowered.

SECTION IV - THEORY OF OPERATION

4-1 GENERAL (Refer to Fig. 4-1 and Fig. 4-2)

4-2 This section describes the major circuitry of the KEPCO KS Power Supply. The purpose of the analysis is to provide the user with a functional understanding of the unit forming thus a basis for successful operation and maintenance.

4-3 While the connecting diagram (Fig. 4-1, Table 4-1) shows the mechanical interconnection of the individual plug-in assemblies of the supply, the block diagram (Fig. 4-2) shows the functional electrical connections.

4-4 CIRCUIT DESCRIPTION

4-5 AC Input Circuit. (Refer to Fig. 4-3) AC power is introduced to the unit through a heavy duty three-wire safety cord with three-prong plug. When AC line switch S101 is closed, C501 which was completely discharged, will charge and its instantaneous peak charging current will close K501 and thereby energize the primary of T201. The relay holding current flows now from the cathode side of CR501 over thermo-switch S-701, over relay contacts (1) and (3), through R502 and finally through the coil of K501. C501 will not completely discharge since the charging potential is still connected. Consequently, when thermo-switch S-701 is opened by over-temperature, the current path through the coil of K501 is interrupted. It's energized state can only be re-established if S101 is opened for a few seconds, thus removing the charging potential from C501 and allowing it to discharge. If S101 is now closed again and the cause for the over-temperature is corrected, allowing S-701 to assume its normally closed position again, recycling of the above described sequence takes place. The primary circuit is further protected from overloads by main-fuse F101 and reference fuse F102.

4-6 Main dc power supply. The main dc power is derived from the secondary winding on T201 with its associated bridge rectifier circuit working into a capacitor input filter. Two of the rectifiers are of the controlled type (SCR's). The main dc power supply delivers the output current and the operating voltages for the pass-elements.

4-7 Pass-Element Circuitry. (Refer to Fig. 4-4)
The pass-elements are connected in series with the negative output lead, so that the unregulated voltage from the rectifier circuit is divided between these power transistors and the dc output of the power supply. By properly "driving" the pass transistors, their equivalent resistance changes and therefore the voltage drop across them is made to change in such a way as to maintain the dc output voltage constant. The base-

drive necessary for this action is supplied by a driver (A6) which itself is driven by a predriver (Q6) which gets its base drive from the output of either voltage or current comparison amplifier.

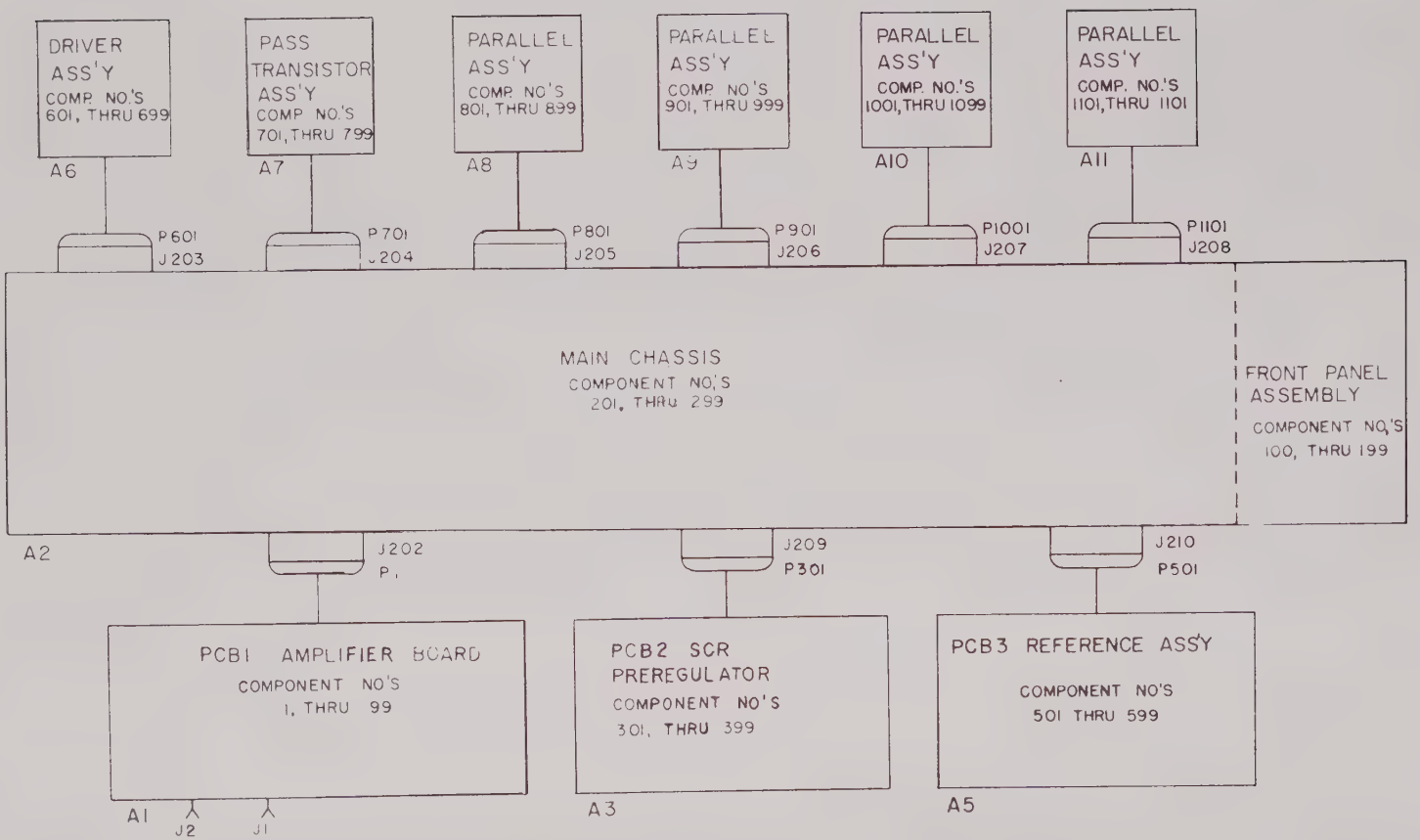


FIG. 4-1 CONNECTING DIAGRAM, KS 60-5 (M)

TABLE 4-1 SUBASSEMBLIES, KS 60-5

COMPONENT SERIES	ASS'Y NO.	PRINTED CIRCUIT BOARD NO.	ASSEMBLY DESCRIPTION
1-99	A1	PCB-1	Plug-in Assembly, Containing: Comparison Bridge, Voltage. Comparison Bridge, Current. Error Voltage Amplifier, Voltage. Error Voltage Amplifier, Current. Automatic Cross-over Stage, (OR-Gate) with cross-over signal jacks.
100	A2		Front Panel Ass'y. contains: Control-Components and Meters. (If units so equipped).
200	A2		Main Chassis Assembly, Containing: Main transformer with power rectifier & assembly pass-elements. PCB-3
300	A3	PCB-2	Preregulator circuit.
400	A4		Not Used.
500	A5	PCB-3	Plug-In Assembly Containing: Printed Circuit board with reference transformer and auxiliary supplies for pre-regulator amplifier and pre-driver collector supply.
600	A6		Plug-In Assembly with driver transistor and its bias resistor.
700	A7		Plug-In Assembly with pass transistor and its series regulator.
800	A8		Plug-In Assembly with pass transistor, its series resistor and a bias resistor.
900	A9		Plug-In Assembly with pass transistor, and series resistor. Over-temperature switch.
1000	A10		Plug-In Assembly with pass transistor, and its series regulator.
1100	A11		Plug-In Assembly with pass transistor, and its series regulator.

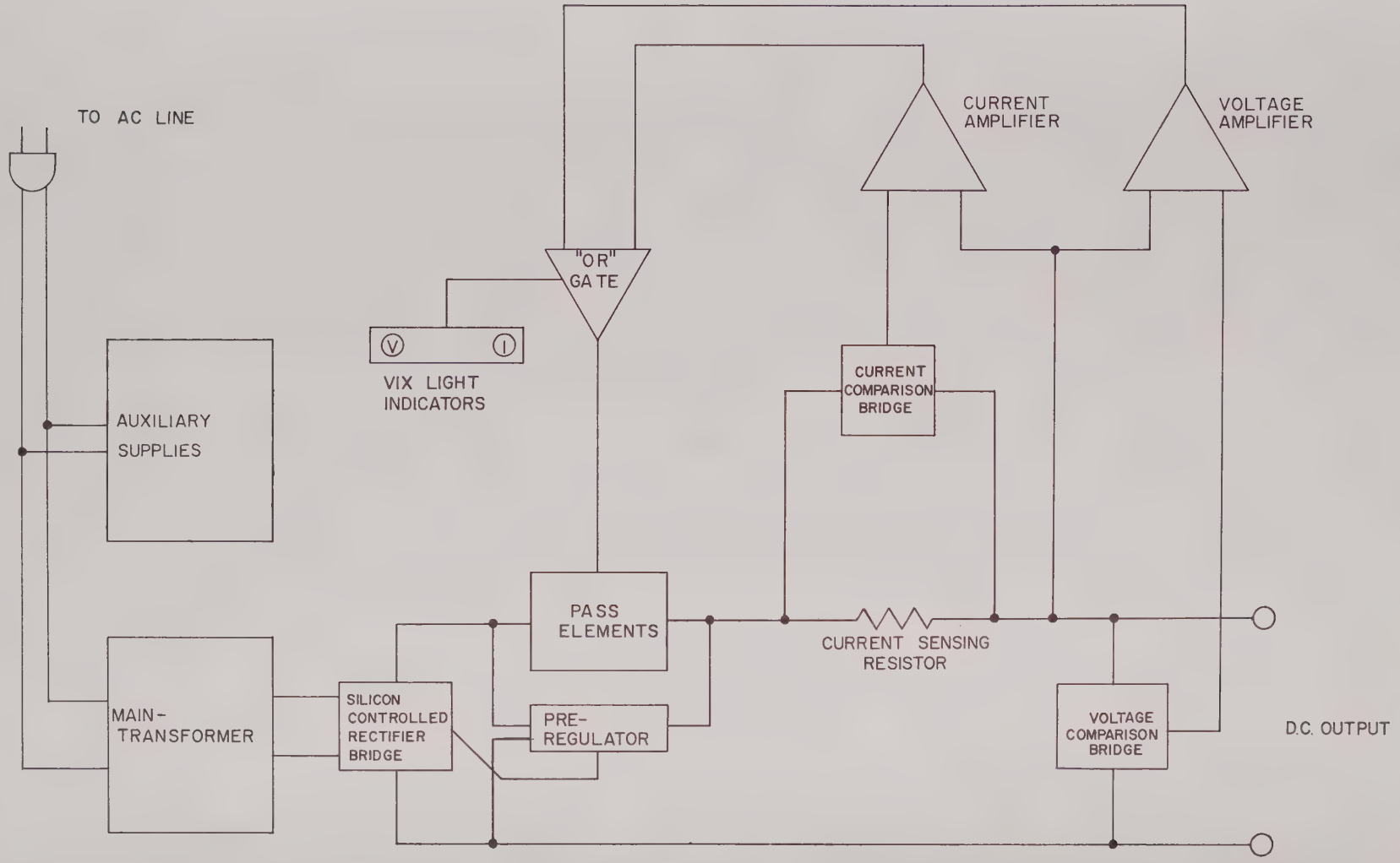


FIG. 4-2 KEPCO KS SERIES POWER SUPPLY, BLOCK DIAGRAM

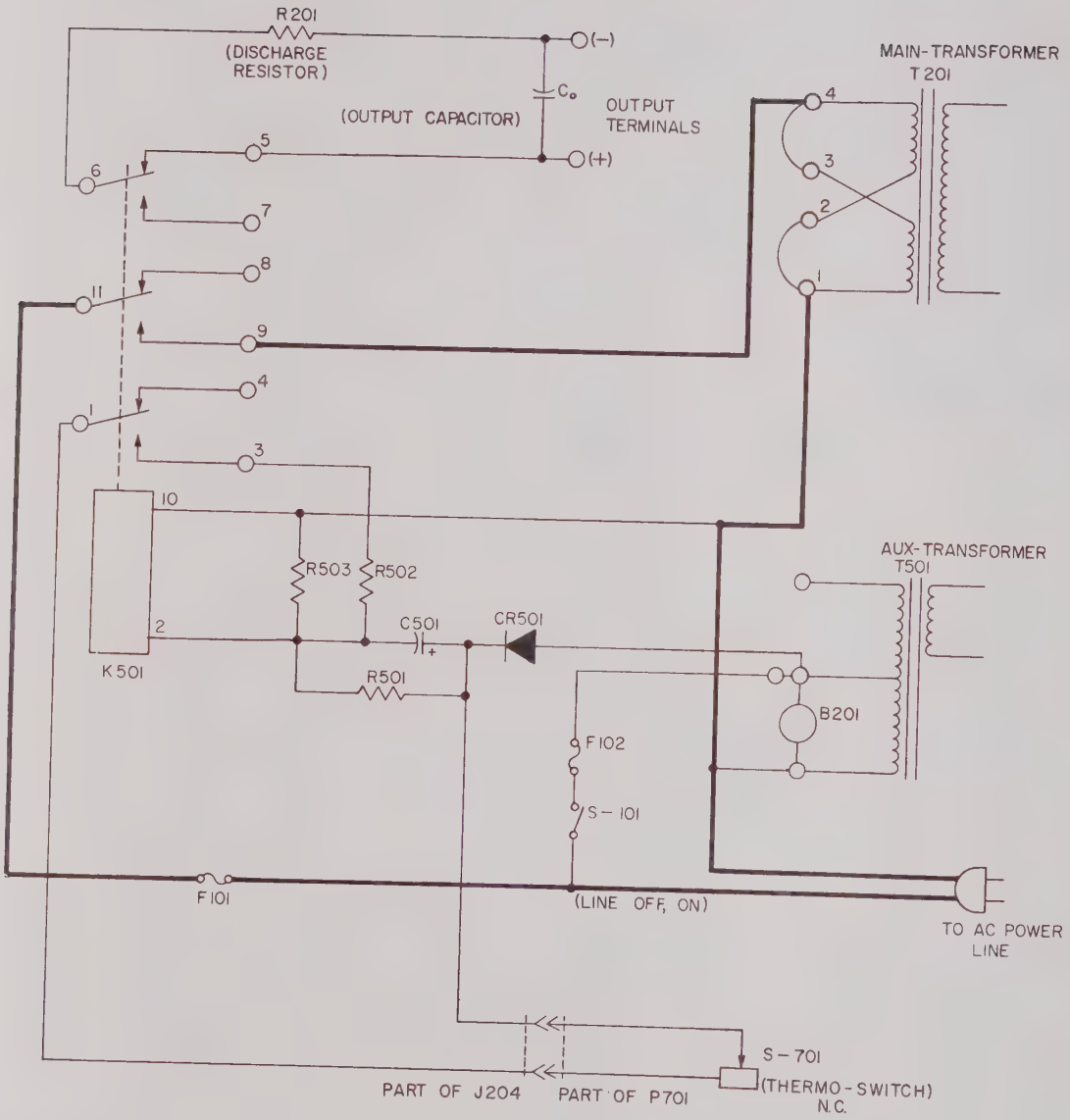


FIG. 4-3 AC INPUT CIRCUIT

KS 3 1/2" - 5 1/4"/34-65

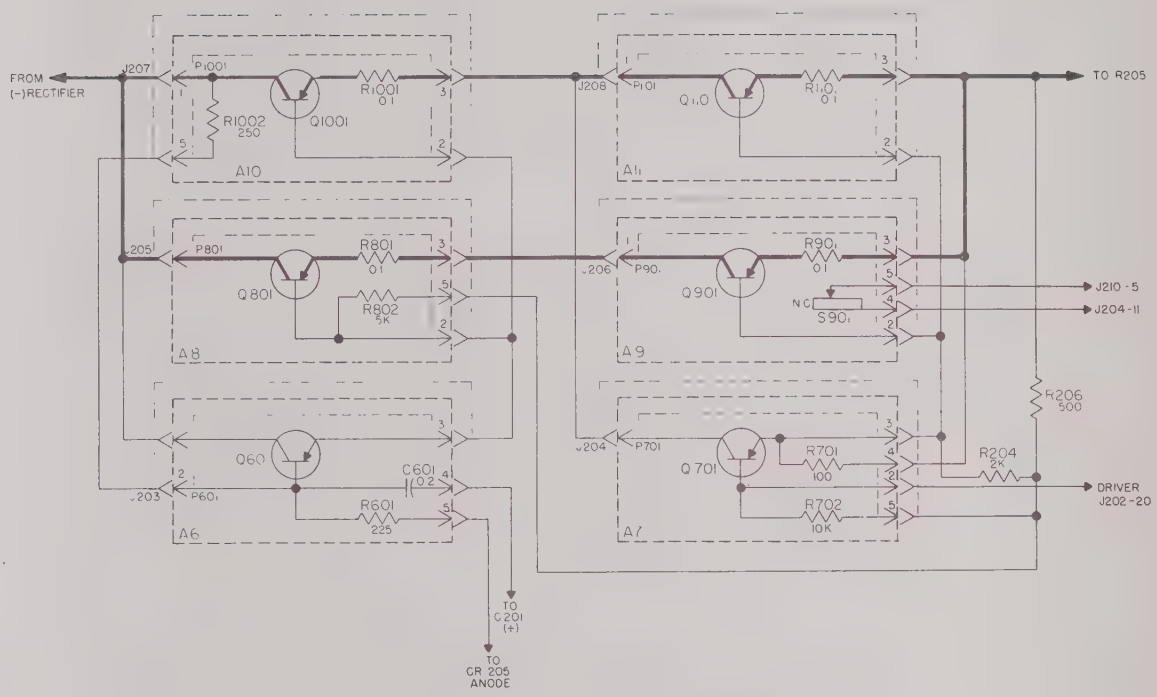


FIG. 4-4 PASS ELEMENT ASSEMBLIES, DETAIL

4-8 Preregulator. In the KS power supply, phase control of an S.C.R. bridge was chosen as a method of pre-regulating the raw dc voltage. According to the output voltage or current required, the S.C.R.'s are commanded to conduct over a greater or smaller portion of their half-cycle. While in conventional supplies much power is lost and has to be dissipated across the pass elements, this power loss is now considerably reduced and a much more efficient system results.

4-9 The preregulator circuitry is located in PCB-2, assembly A3. The assembly is in the form of a printed circuit board whose connector P301 mates with main-chassis mating plug J209.

4-10 In order to compensate for the non-linear transfer function of the S.C.R. bridge, and to cause the pre-regulator to track the output voltage at full load (where pass element dissipation is maximum), a sample of the unregulated output voltage (E_u) is subtracted from the pass element voltage (V_x) and the algebraic sum of the two voltages is sensed at points P1 - Po (See Fig. 4-5). The sensed voltage is compared to the reference source CR308 through a voltage divider network and the derived error signal applied to the base of Q303, which controls the slope of the ramp timing circuit.

4-11 For a given arbitrary input signal, C306 is charged by the collector current of Q303 to a pre-determined voltage level. At this specific potential, unijunction transistor Q302 triggers, supplying a negative pulse to Q304, the pulse amplifier stage. The positive excursion at the collector of Q304 constitutes the firing pulse for both S.C.R.'s. The complete discharge of ramp capacitor C306 is accomplished through Q301. This stage receives a synchronizing pulse from clipper diode CR307 at the precise moment the sine wave crosses the zero axis. (t=0) Q301 conducts upon receiving the sync. pulse and C306 discharges at this moment, and simultaneously a new cycle is started and C306 starts to charge again.

4-12 Fig. 4-6 shows the timing wave forms and their relationship to each other for two conditions of output voltage or current. The significant difference between the two conditions is the length of the timing ramp wave form across C306 and the resulting difference of firing angle of the S.C.R.'s.

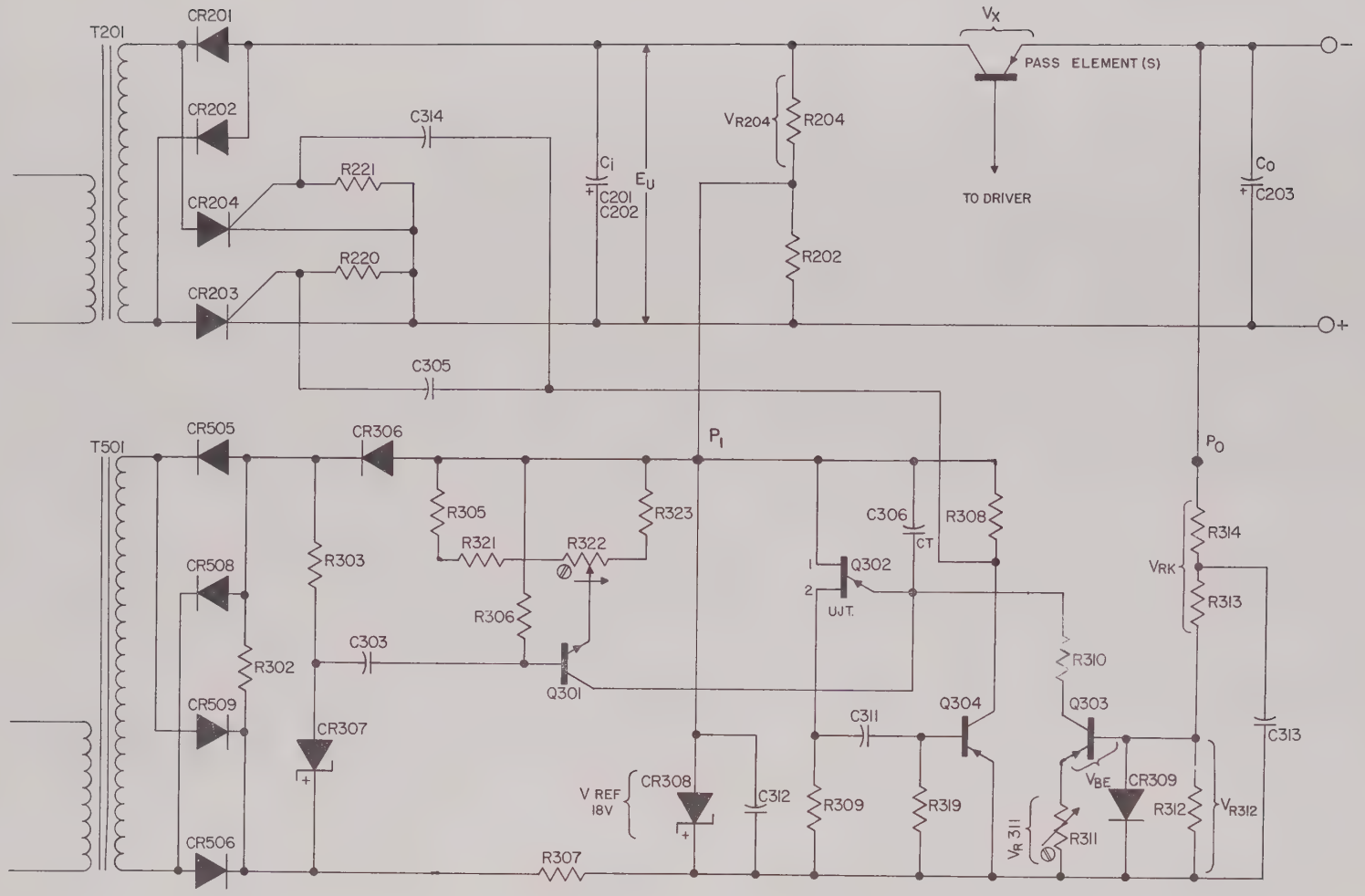


FIG. 4-5
PRE-REGULATOR CIRCUIT
SIMPLIFIED

$(V_X + V_{RK} + V_{R312}) = (V_{REF} + V_{R204})$

$V_{R312} = (V_{R311} - V_{BE})$

$V_{R204} \propto E_U$

C_T = TIMING RAMP CAPACITOR

C_i = INPUT CAPACITOR

C_o = OUTPUT CAPACITOR

E_U = UNREGULATED OUTPUT

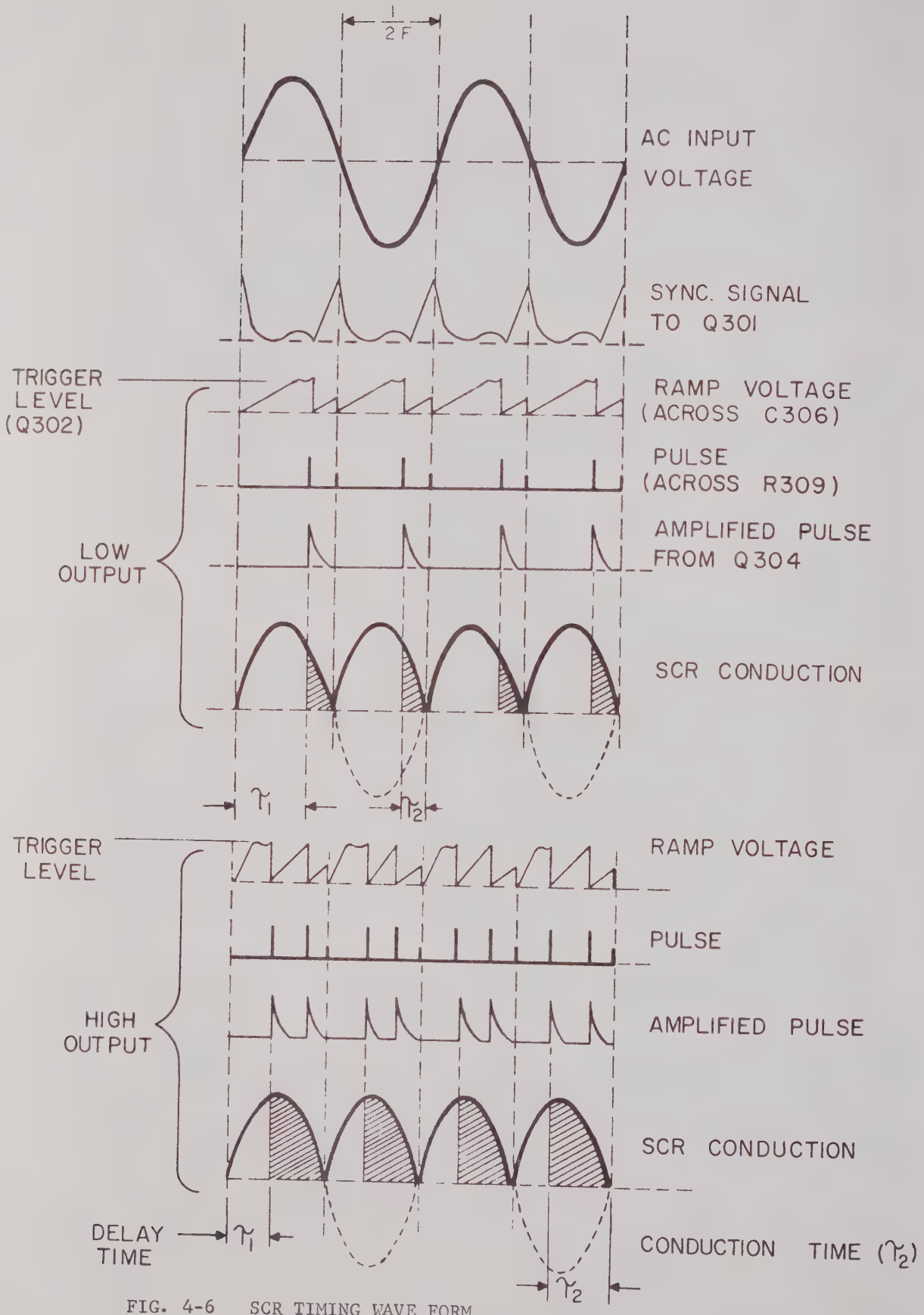


FIG. 4-6 SCR TIMING WAVE FORM

4-13 CONTROL SECTION (Refer to Fig. 4-7)

4-14 The control circuitry of the KS power supply is located on PCB-1, assembly A1. This assembly is in the form of a printed circuit board, whose connector P1 connects it to the main chassis and auxiliary circuitry through J202. (Refer to Fig. 4-1 & Fig. 4-2) Electrically the control circuitry consists of several interrelated sections which are described in detail below.

a) Control Circuit Power Supply. (Refer to Fig. 4-7) This highly regulated supply delivers the fixed operating voltages for the voltage mode and current mode amplifiers, as well as the reference voltages for the voltage mode and current mode comparison bridges. It is derived from a centertapped winding on T501 and consists of a full-wave rectifier with capacitor-input filter (CR503, CR504, C503), a series current regulator stage (Q1), and the zener regulator diodes CR10 and CR11 for the minus and plus 18 volts respectively. The negative and positive 18 volt supplies are filtered by C505 and C504 respectively. The voltage reference diode (CR14) is fed from the negative 18 V source and the current reference (CR15) from the positive 18 V source.

b) Comparison Bridges. In the Kepco KS power supplies two separate control channels are used, each with it's own comparison bridge circuit and its associated error signal amplifier. The voltage mode comparison bridge senses the output voltage across the output terminals of the power supply. (Except when using remote error sensing; then the bridge senses directly across the load.) The current mode comparison bridge senses the voltage across the current sensing resistor R_S. Each bridge compares its sensing voltage to its own reference voltage.

c) Current Mode Amplifier. An unbalance in the current mode comparison bridge results in an error signal which is transferred to input transistor Q10, and amplified by Q9 and Q13. It arrives at gate transistor Q5 as a large negative excursion.

d) Voltage Mode Amplifier. An unbalance in the voltage mode comparison bridge results in an error signal transferred to input transistor Q2 and is amplified by Q3. It arrives at the base of gate transistor Q4.

e) OR Gate. The gate transistors Q4 and Q5 act like a two pole switch. The transistor with the larger negative signal on its base will conduct, cutting the other one off. The transistor which conducts, be it Q4 or Q5, will in turn drive its associated mode-indicator amplifier companion into conduction, which then will energize either DS101 or DS102, the mode indicator.

f) Common Amplifier and Driver. The signal predominant in the above description, may it originate in the voltage or current mode comparison bridge, will be further amplified by Q7 and transferred to the pre-driver Q6 which, as an emitter-follower, supplies the necessary drive to the main-driver and the pass-elements.

g) Q8 is a bias-setting stage for the rest of the transistors in the amplifier. Its base provides a convenient point for the start of a dc analysis of the system.

h) Automatic Crossover Operation. Automatic mode switching in the KS power supplies is caused by an unbalance in one of the comparison bridges as discussed above. The operating mode of the power supply is therefore mutually dependent upon the load resistance and the setting of the voltage and current controls. The "Crossover Point" is defined by the ratio of the voltage and current setting which equals the load resistance. If for example, the load current due to a specific load resistance, is larger than the current control setting of the supply, the current mode comparison bridge will produce the larger error signal and the power supply will automatically switch to current mode operation as described above. At any load resistance value causing an output current smaller than the set value at the current control, the power supply will operate in voltage mode.

i) VIX Crossover Signals. Automatic Crossover from one mode of operation to the other is indicated by two signal lamps located on the front panel. (DS101, DS102). The crossover signal is also available at two jacks (J1, J2) on the rear of the unit. This signal may be taken out and converted into a heavy duty relay closure for signal purposes by means of the KEPCO VIX-1C Relay or any other device sensitive to a signal of ± 8V DC. (nominal), 1 ma.

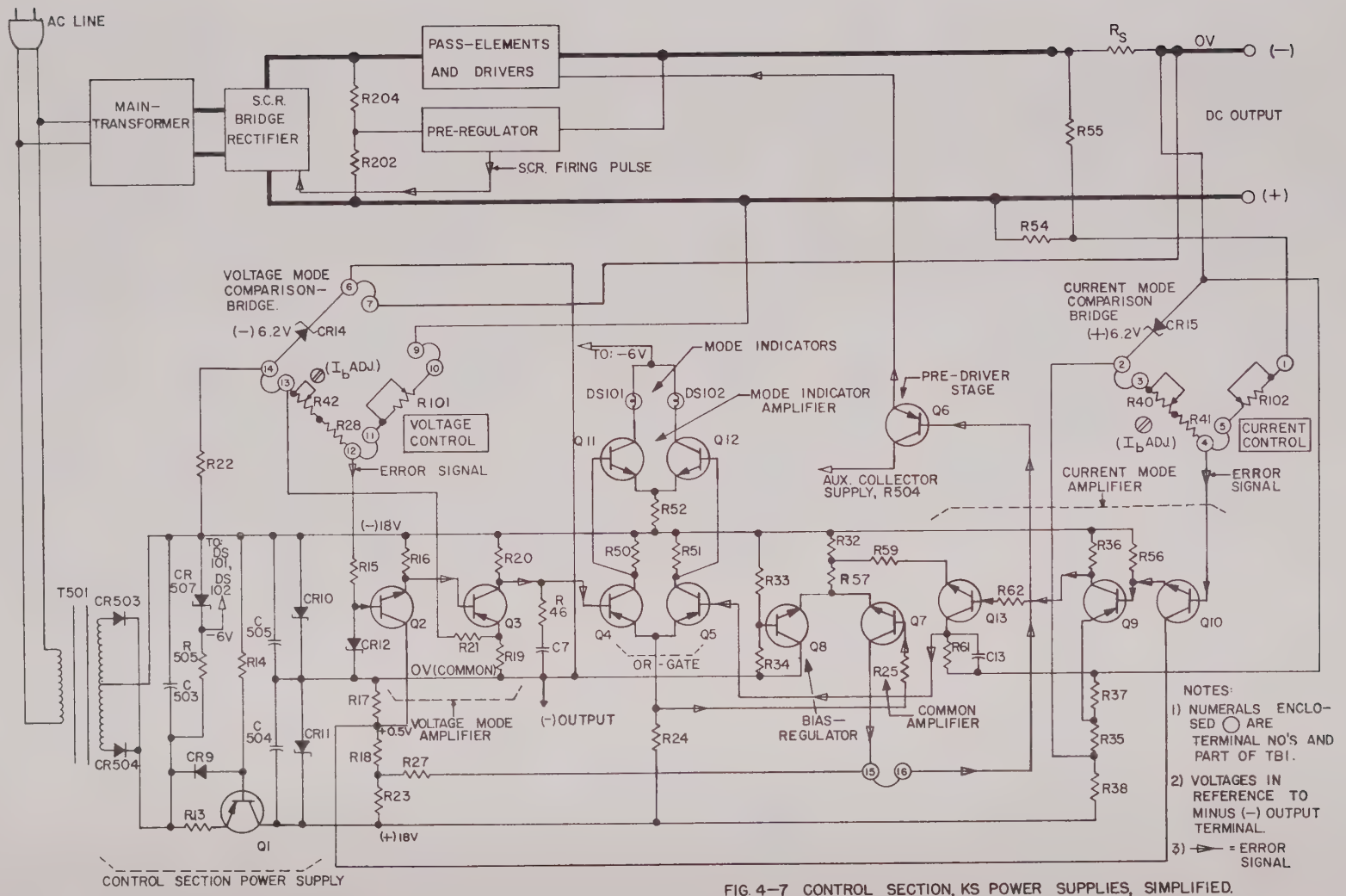


FIG. 4-7 CONTROL SECTION, KS POWER SUPPLIES, SIMPLIFIED.

SECTION V - MAINTENANCE

5-1 GENERAL

5-2 This section contains information for the maintenance, internal adjustments and test-measurements of the KEPCO Series KS Power Supply.

5-3 PRECAUTIONS

5-4 No part replacements or adjustments, other than described in this section, should be made on the instrument. Replacements or adjustments made without understanding the effects may cause serious damage to the Power Supply.

5-5 TEST EQUIPMENT REQUIRED

5-6 The following is a listing of the test equipment required to measure some important parameters and make all necessary adjustments on the KEPCO KS Power Supplies:

a) KEPCO AC Line Step Device Model 920B or variable transformer capable of adjusting the power line from 105V to 125V AC and rated to deliver the maximum input current for the instrument under test. (Refer to Table 1-1).

b) Resistor load, adjustable to load the power supply to 10%, 50% and 100% in both, voltage and current operating modes and equipped with a shorting switch.

c) Voltage Monitor. KEPCO Regulation Analyzer 901D, differential or digital voltmeter with a resolution of at least 1 mv and a range covering the maximum output voltage of the power supply under test.

d) RMS reading voltmeter for ripple monitoring, Ballantine Model 320A or it's equivalent. (Ripple meter self-contained in KEPCO 901D).

e) Oscilloscope for monitoring SCR firing pulses and output ripple observance. (Tektronix, Model 502B or equivalent)

f) Multimeter for measuring pass element voltage and general trouble shooting measurements. 20K ohm/V, Weston Analyzer Model 980 or it's equivalent.

g) Precision DC ampere meter with a range covering the maximum output current of the Model under test. (Weston Model 931 or equivalent)

5-7 DISASSEMBLY (Refer to Fig. 1-3)

5-8 Internal adjustments on the KS power supplies may require partial disassembly of the unit. This is readily accomplished by following the steps given below. Proceed in reverse order for re-assembly.

a) Top Cover Plate. Held by six (6) Phillips-head 6/32 machine screws. Loosen screws and remove plate.

b) Side Carrying Handles (on 8 3/4" high units only). Held by eight (8) Phillips-head 10/32 machine screws each. Loosen screws and remove handles.

c) Skid Rails (on 8 3/4" high units only). Held by three (3) flat head 10/32 machine screws on each side of case bottom. Loosen screws and remove rails and stand-offs.

d) Bottom Cover. (on 8 3/4" high units, removal possible only after skid rails have been dismounted). Held by six (6) Phillips-head 6/32 machine screws. Loosen screws and remove plate.

e) Rear Cover. Held by eight (8) Phillips-head 6/32 machine screws. Loosen screws and remove cover plate.

5-9 INTERNAL ADJUSTMENT PROCEDURES

5-10 The internal adjustments for maximum output current and voltage are located on assembly A1 as shown in Fig. 2-3 and Table 2-2. These adjustments vary the bridge current (I_b) in both, voltage and current comparison bridge. They are factory adjusted to a value 2% above the maximum rated voltage or current with the respective front panel controls fully clockwise. These controls require resetting only if previously changed for programming purposes or following replacement of related circuit components.

5-11 PROCEDURE, VOLTAGE CONTROL ADJUSTMENT

a) Remove top and rear cover plates by loosening holding screws. (Refer to Paragraph 5-7)

b) Connect precision voltmeter of suitable range across the front or rear output terminals of the power supply. Turn both voltage and current front panel controls to their maximum clockwise position.

c) Turn power supply "on". Locate R42 "Maximum Voltage Control" on Assembly A1, (Fig. 2-3), and adjust output voltage to 2% above maximum rated value for the particular model, as observed on the external, precision voltmeter.

d) Replace cover plates and holding screws.

5-12 PROCEDURE, CURRENT CONTROL ADJUSTMENT

a) Remove top and rear cover-plates by loosening holding screws. (Refer to Paragraph 5-7).

b) Connect a precision ampere meter of suitable range across the rear output terminals of the supply. Turn the front panel voltage control to its maximum clockwise, and the front panel current control to its maximum counter clockwise position.

c) Turn power supply "on", and slowly turn the front panel current control clockwise until its maximum clockwise position is reached.

d) Locate "Maximum Current Adjust" control on assembly A1 (Refer to Fig. 2-3) and adjust output current to 2% above its maximum rated value for the particular model, as observed on the external precision ampere meter.

e) Replace cover plates and holding screws.

NOTE: The following internal adjustments are precision factory set and should not be altered unless required by replacement of components associated with the controls.

5-13 PROCEDURE, INTERNAL AMMETER CALIBRATION (Applicable on metered units rated for an output current rating greater than 15A DC.)

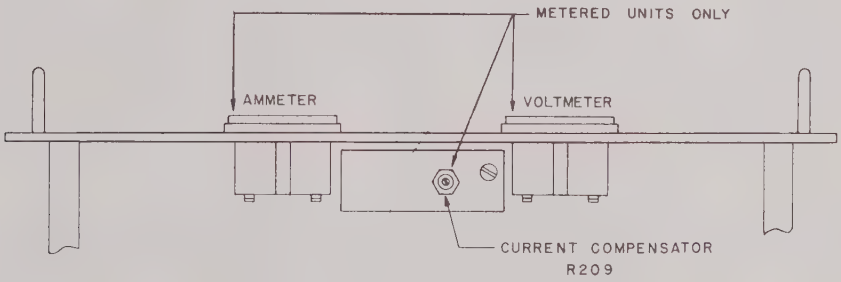


FIG. 5-1 LOCATION OF AMMETER CALIBRATION RESISTOR AND CURRENT COMPENSATOR

a) Remove top and rear cover plates by loosening holding screws as indicated in Paragraph 5-7.

b) Turn Current Control on the front panel to its maximum counter clockwise position.

c) Connect precision ampere meter across the rear output terminals of the power supply.

d) Turn power supply "on" and slowly advance the Current Control clockwise until maximum output current is reached.

e) Compare panel meter reading with the precision meter readings and correct for discrepancies by loosening lock-nut on R215 (Refer to Fig. 5-1) and adjusting it to the desired value. Relock R215.

5-14 PROCEDURE, CURRENT REGULATION COMPENSATOR ADJUSTMENT

5-15 Potentiometer R209 in conjunction with its associated components (R210, R54, R55) compensates for the internal loading of the voltmeter and the voltage bridge circuit when the power supply is operating in the constant current mode. Adjustment of this control is required only when R209 or its associated components must be replaced or when other changes of internal loading of the power supply take place.

a) Equipment Required: (Refer to Paragraph 5-5)

b) Connect test equipment as shown in Fig. 5-5.

c) With the power supply in its current regulation mode, and drawing approximately 10% of its maximum load current, measure the voltage drop across R_S.

d) Close S-1 and note delta V, the difference between the readings with S-1 open and closed. Rotate R209 as to minimize delta V on repeated tests.

5-16 PROCEDURE, PRE-REGULATOR ADJUSTMENTS

5-17 Replacement of parts in the pre-regulator section of the power supply may necessitate the readjustment of the two controls in this section.

a) Instruments Required: (Refer to Paragraph 5-5)

b) Connect the resistor load to the rear-output terminals of the power supplies. (Refer to Fig. 5-6)

c) Connect multimeter and oscilloscope as indicated in Fig. 5-2. (Main Chassis Component location).

CAUTION: To avoid ground loop shorting effects, use differential input connection on the oscilloscope.

d) Connect power supply to the variable transformer or line-step device and adjust input voltage to 105V AC.

e) Locate both, the "Pass Voltage Adjust" (R311) and the "Line Voltage Correction" adjustment (R322) on assembly A3 (Fig. 2-3). Set both controls to their approximate mid-position.

f) Turn power supply "on", and set to its maximum rated output voltage and current by turning both front panel controls to their maximum clockwise position. Slowly increase the load until maximum output current is reached. Observe voltmeter across the main-pass elements. If the voltage (V_X) at any time tends to fall below 2 volts, re-adjust R311 to maintain V_X above this value, otherwise loss of regulation will occur.

g) When maximum output current is reached, slightly back off on the Current Control to bring supply into current mode operation as indicated by the current VIX control lamp.

h) Observe the oscilloscope. A regular series of firing pulses with a frequency of 120 cps should be observed with the scope "Synch Control" on "Line".

i) Adjust R311, so that the pass voltage (V_X) is 3 volts.

j) Changing the AC input voltage from 105V AC to 125V AC, observe the change in pass-voltage (ΔV_X) on the voltmeter. This change should be approximately 1.5 volts and can be adjusted by turning R322. R311 interacts with the adjustment of R322 and must be reset to 3 volts. The adjustment procedure is repeated until the change in ΔV_X while changing the line between 105V and 125V remains below 1.5 volts and a regular, stable series of firing pulses of 120 cps is observed.

k) Turn power supply "off" and place a short circuit across the output.

l) Turn power supply "on" and observe firing pulses and the change in V_X as the line is varied between 105V and 125V AC. V_X may be slightly higher, but ΔV_X should be approximately the same and the firing pulses must be 120 cps and stable. This concludes the pre-regulator adjustment.

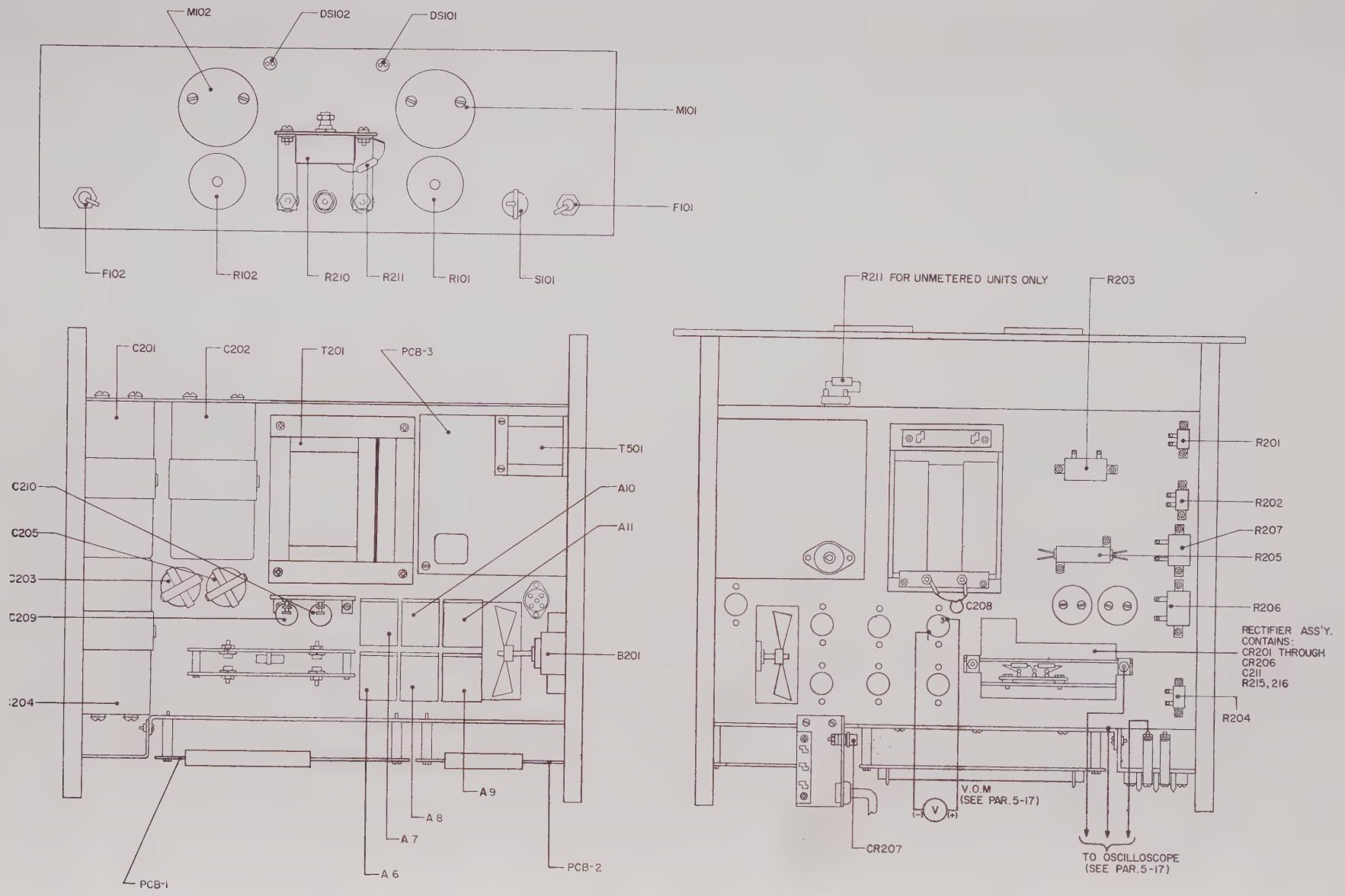


FIG. 5-2 COMPONENT LOCATION, MAIN CHASSIS ASSEMBLY (A2)

5-18 TROUBLE SHOOTING

5-19 Contrary to popular opinion, modern, high performance power supplies today have reached a state of sophistication that requires thorough understanding of the problems involved in repairing complex, solid state circuitry. Servicing beyond simple parts replacements should consequently be attempted only by personnel thoroughly familiar with solid state component techniques and with experience in closed loop circuitry.

5-20 Trouble-shooting charts, showing resistance and voltage readings, are of very limited usefulness with feedback amplifiers and are not included here. Instead a detailed circuit description (Section IV), parts location diagrams, simplified functional schematics of the several circuit sections, and a main schematic with all significant voltage readings is presented.

5-21 The following basic steps in a case of power supply malfunctioning may also be found useful:

a) If power supply does not function at all: Check all powerline connections and fuses and make certain, power supply is connected to the correct line voltage (it is normally delivered for 115V AC operation).

b) If power supply fuses keep blowing or circuit breakers keep tripping, check pass-elements (without removing from assembly) by placing an ohm-meter across the emitter and collector. The emitter-collector resistance will be low in one direction and higher in the other, the ratio being approximately 5:1. If resistance is equally low in both directions (short circuit) the pass-element must be replaced.

c) If the power supply is basically functioning, but poor performance is evident, inspect the test set-up to make certain the source of the trouble is not external.

d) Poor regulation in any of the regulating modes is usually traceable to incorrectly connected loads or faulty measurement techniques. Perform measurements as described in Paragraph 5-23 and follow the connecting diagrams.

e) Oscillation of the output voltage or output current is often due to a load with a large inductive component. Twisted loadwires of sufficient diameter and held as short as practical, are often the solution to the problem. In severe cases, a capacitor directly across the load will frequently help.

5-22 KEPCO Field Engineering Offices or the KEPCO Repair Department will be available for consultation or direct help in difficult service or application problems.

5-23 POWER SUPPLY MEASUREMENTS

5-24 Measurements of the significant parameters of a power supply is a requirement for incoming inspection, periodic maintenance, or after component replacement. Since some of the measurements require special techniques to insure correct results, suggestions for their performance are given below:

a) Instrumentation

Refer to Paragraph 5-5 for the necessary test equipment.

b) The proper location of the instrument leads when measuring regulation is of the utmost importance. Improperly placed leads may measure voltage drop due to contact resistance and load current flow and thus lead to incorrect results. This can be avoided by the four terminal network technique. Fig.s 5-3 to 5-6 show clearly how this technique is employed in regulation measurements. The principle is very simple but important: Do not measure voltage drops due to load current.

c) Voltage Regulation is definced as the amount of output voltage change resulting from a specified change in line voltage or from a change in load resistance. It can be expressed as an absolute change (ΔV) or as a percentage in reference to the total output voltage E_o;

$$\% \text{ Voltage Regulation} = \frac{\Delta V}{E_o} \quad (100\%)$$

d) Current Regulation is defined as the amount of output current change resulting from a specified change in line voltage or from a change in load resistance. It can be expressed as an absolute change (ΔI), or as a percentage in reference to the total output current I_o;

$$\% \text{ Current Regulation} = \frac{\Delta I}{I_o} \quad (100\%)$$

e) Ripple. An oscilloscope of suitable sensitivity, or a true RMS indicating meter may be used to measure the ripple at the output of the power supply. Suitable DC blocking must be provided externally, if the test instrument is not equipped with a suitable input. A 0.1 mfd capacitor of sufficient working voltage is generally adequate. If an oscilloscope is used only, the ptp/RMS ratio, which

for a pure sine wave is close to 2.83:1, can be approximated for the broken wave-form of a series regulator type power supply as 3:1.

CAUTION: Due to the low signal levels, ripple pick-up problems are especially accute when measuring ripple in the current mode. The use of completely shielded sensing resistors and load cables may be necessary to get valid readings.

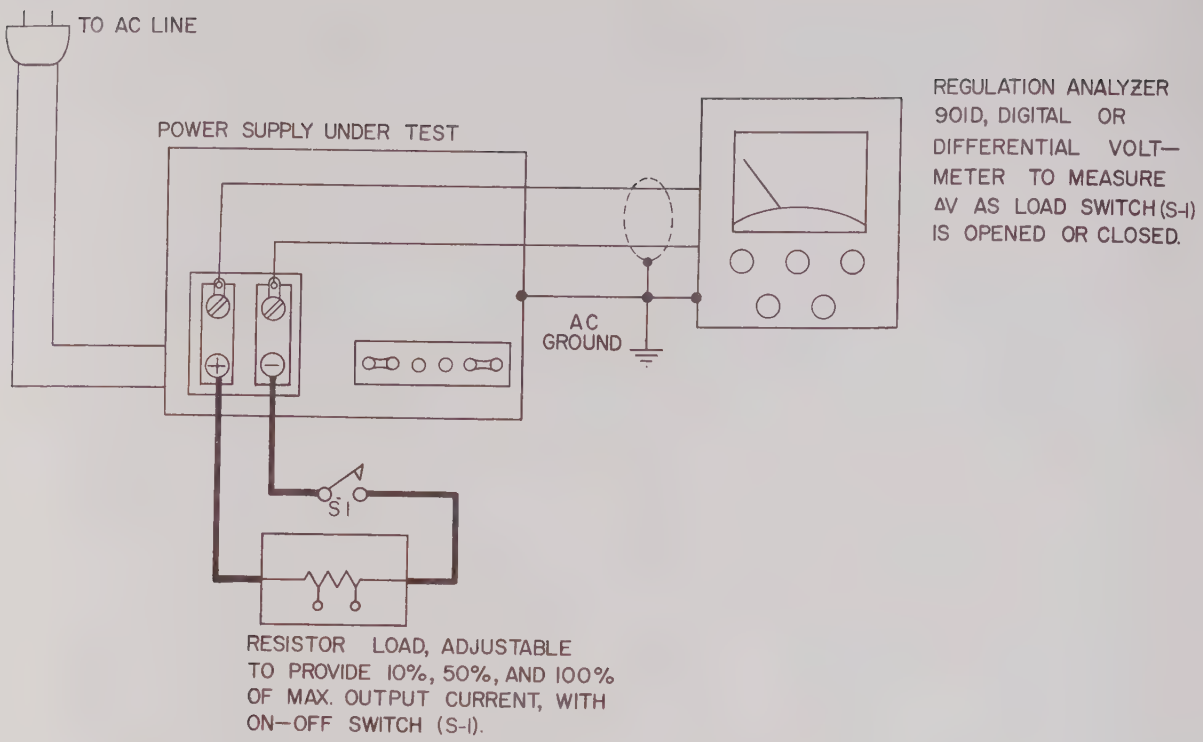

TO AC LINE
POWER SUPPLY UNDER TEST
REGULATION ANALYZER 901D, DIGITAL OR DIFFERENTIAL VOLT-METER TO MEASURE ΔV AS LOAD SWITCH (S-1) IS OPENED OR CLOSED.
AC GROUND
S1
RESISTOR LOAD, ADJUSTABLE TO PROVIDE 10%, 50%, AND 100% OF MAX. OUTPUT CURRENT, WITH ON-OFF SWITCH (S-1).

FIG. 5-3 MEASURING LOAD REGULATION (VOLTAGE MODE) WITHOUT REMOTE ERROR SENSING

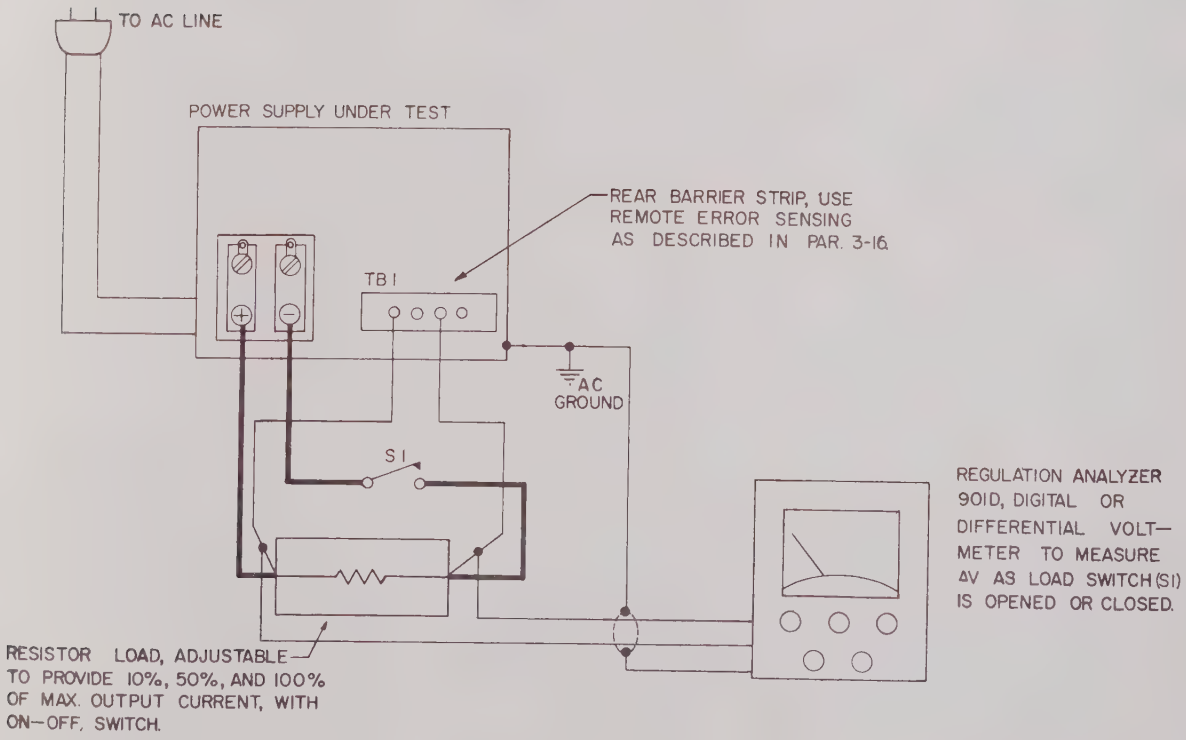

TO AC LINE
POWER SUPPLY UNDER TEST
REAR BARRIER STRIP, USE REMOTE ERROR SENSING AS DESCRIBED IN PAR. 3-16.
TB1
AC GROUND
S1
REGULATION ANALYZER 901D, DIGITAL OR DIFFERENTIAL VOLT-METER TO MEASURE ΔV AS LOAD SWITCH (S1) IS OPENED OR CLOSED.
RESISTOR LOAD, ADJUSTABLE TO PROVIDE 10%, 50%, AND 100% OF MAX. OUTPUT CURRENT, WITH ON-OFF, SWITCH.

FIG. 5-4 MEASURING LOAD REGULATION (VOLTAGE MODE) DIRECTLY AT THE LOAD

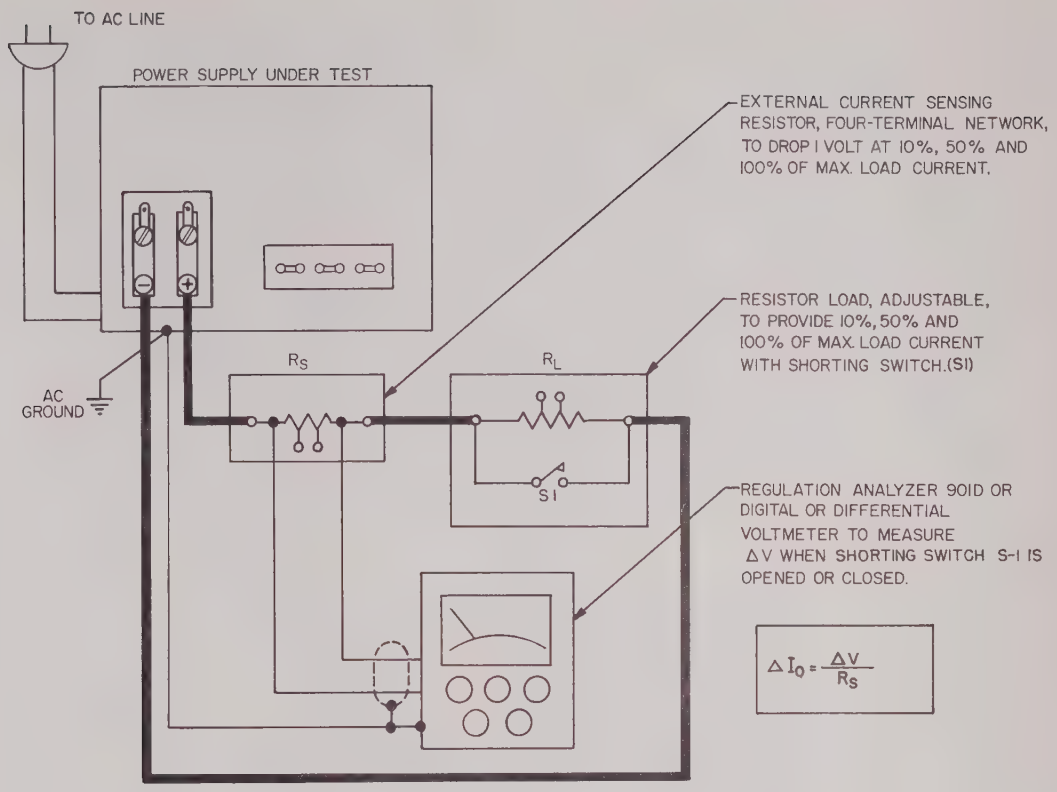

TO AC LINE
POWER SUPPLY UNDER TEST
EXTERNAL CURRENT SENSING RESISTOR, FOUR-TERMINAL NETWORK, TO DROP 1 VOLT AT 10%, 50% AND 100% OF MAX. LOAD CURRENT.
RESISTOR LOAD, ADJUSTABLE, TO PROVIDE 10%, 50% AND 100% OF MAX. LOAD CURRENT WITH SHORTING SWITCH.(S1)
R_S
R_L
AC GROUND
S1
REGULATION ANALYZER 901D OR DIGITAL OR DIFFERENTIAL VOLTMETER TO MEASURE ΔV WHEN SHORTING SWITCH S-1 IS OPENED OR CLOSED.
$\Delta I_0 = \frac{\Delta V}{R_S}$

FIG. 5-5 MEASURING LOAD REGULATION (CURRENT MODE)

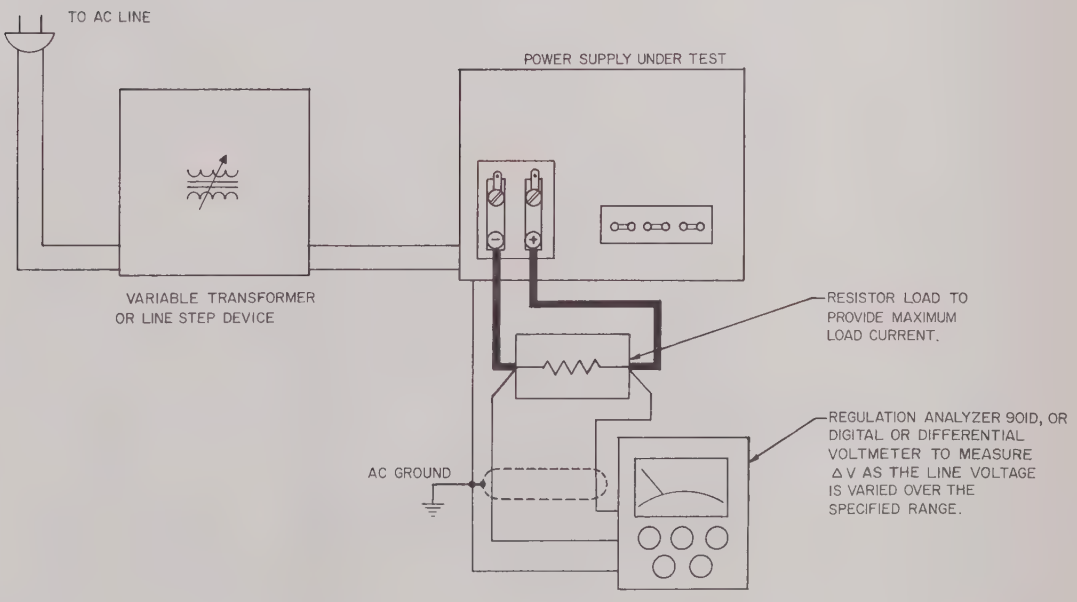
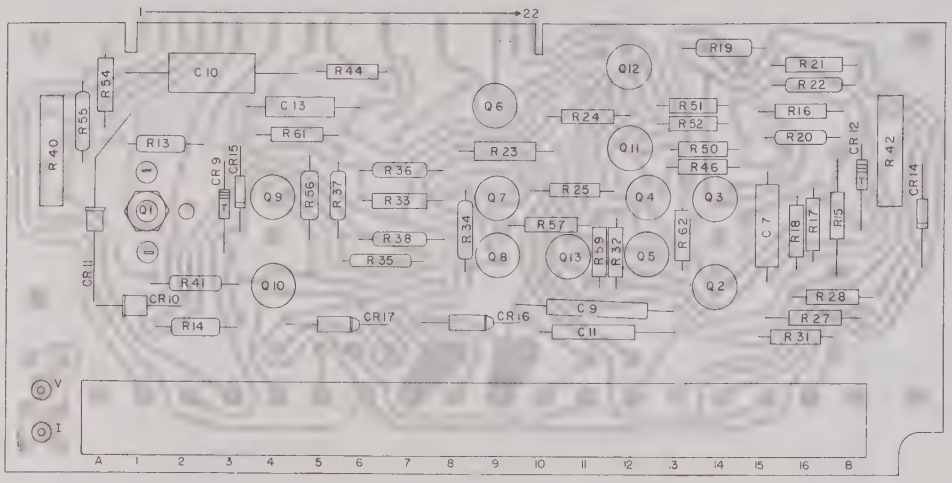
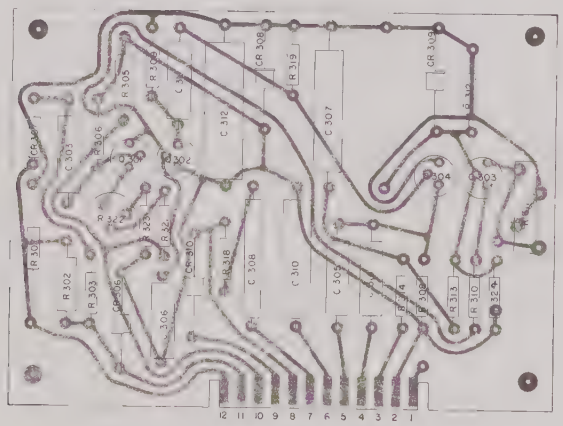

TO AC LINE
POWER SUPPLY UNDER TEST
VARIABLE TRANSFORMER OR LINE STEP DEVICE
RESISTOR LOAD TO PROVIDE MAXIMUM LOAD CURRENT.
REGULATION ANALYZER 901D, OR DIGITAL OR DIFFERENTIAL VOLTMETER TO MEASURE ΔV AS THE LINE VOLTAGE IS VARIED OVER THE SPECIFIED RANGE.
AC GROUND

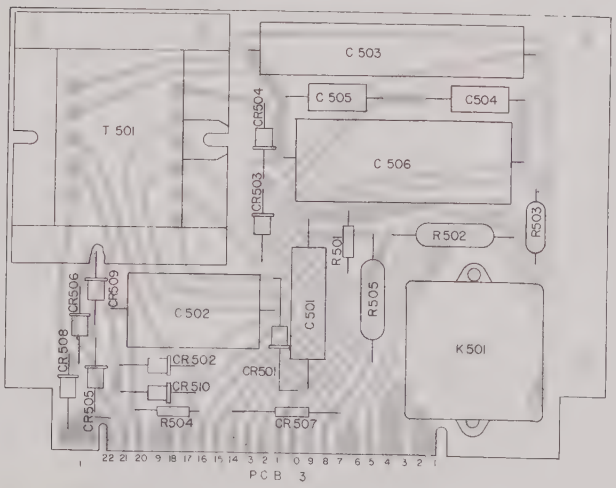
FIG. 5-6 MEASURING LINE REGULATION (VOLTAGE MODE)



A1



A2



A5

FIG. 5-7 COMPONENT LOCATION ASSEMBLIES A1, A2 AND A5

FIG. 5-8 MAIN SCHEMATIC, KS 60-5(M)

NOTES

1. KSOI IS A PLUG-IN TYPE RELAY, WITH AN 11 PIN PLUG. THE NUMBERS REPRESENT PIN NUMBERS.
2. ALL RESISTOR VALUES ARE IN OHMS, K=1,000. ALL CAPACITOR VALUES ARE IN MICROFARADS, K=1,000.
3. VOLTAGE READINGS IN RECTANGLES ( ) ARE TYPICAL VALUES FOR VOLTAGE MODE OPERATION WITH ACLINE AT 115V. DC OUTPUT VOLTAGE SET TO MAX-MUM, AND AT NO LOAD MEASUREMENTS REFERRED TO (-) OUTPUT TERMINAL.
4. VOLTAGE READINGS IN (S) SIDED SYMBOLS ( ) ARE TYPICAL VALUES FOR CURRENT MODE OPERATION AT MAXIMUM OUTPUT VOLTAGE AND CURRENT MEASUREMENT REFERRED TO (-) OUTPUT TERMINALS.
5. M01, M02 IN METERED UNITS ONLY. R211 IS USED IN UNMETERED UNITS ONLY
6. ORDER REPLACEMENT PARTS BY KEPCO PART NUMBER SEE PARTS LIST
7. VOLTAGE READING WHICH APPLY TO NOTES 3 & 4 ARE TYPICAL AND SUBJECT TO COMPONENT TOLERANCES

TB1 (REAR BARRIER STRIP)

CURRENT BRIDGE: CURRENT SENSE, REF VOLTAGE, REF RESISTOR, NULL JCT, CURRENT CONTROL, (-) ERROR SENSING

VOLTAGE BRIDGE: (+) ERROR SENSING, VOLTAGE CONTROL, NULL JCT, REF RESISTOR, REF VOLTAGE

CHASSIS

PARALLEL OPERATION: AMP OUT, DRIVER INPUT

EM05545 12-10-65

AMPLIFIER BOARD, PCB#1, ASS'Y A1, MODEL KS 60-5 (M) Code 11-1864

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
C7,13	2	Capacitor,Mylar,Pigtail 0.4 µf, 200 v, 10%	TRW Type X663F	117-0128
C9	1	Capacitor,Mylar,Pigtail 0.1 µf, 200 v, 10%	TRW Type X663F	117-0363
C10	1	Capacitor,Mylar,Pigtail 0.2 µf, 200 v, 10%	TRW Type X663F	117-0236
C11	1	Capacitor,Mylar,Pigtail 0.5 µf, 200 v, 10%	TRW Type X663F	117-0123
CR9,12	2	Zener Diode	Transitron SV125	121-0028
CR10,11	2	Zener Diode	Motorola 1N3026B	121-0036
CR14,15	2	Zener Diode	International Rect. 1N821	121-0041
CR16,17	2	Rectifier,Silicon,Pigtail	Solitron 124-0178	124-0178
Q1	1	Transistor,PNP	Delco 2N174	119-0016
Q2,7,8,10, 11,12,13	7	Transistor,Silicon,NPN	General Electric 2N338	119-0054
Q3,4,5,6,9	5	Transistor,Silicon,PNP	Hughes 2N1131A	119-0055
R13	1	Resistor,Fixed,Power,Axial 125 ohm, 3 w, 5%	Tepro Electric TS3C	115-1467
R14	1	Resistor,Fixed,Power,Axial 6 K ohm, 3 w, 3%	Hardwick Hindle 9/16 GA6K LTC	115-1155
R15	1	Resistor,Fixed,Molded 560 ohm, 1/2 w, 10%	Allen Bradley EB5611	115-0451
R16,56	2	Resistor,Fixed,Precision,WW 36 K ohm, 2 w, 5%	Tepro Electric TS2C	115-1313
R17,52,59	3	Resistor,Fixed,Molded 100 ohm, 1/2 w, 10%	Allen Bradley EB1011	115-0626
R18	1	Resistor,Fixed,Molded 430 ohm, 1/2 w, 5%	Allen Bradley EB4315	115-0581
R19,37	2	Resistor,Fixed,Precision,WW 10 ohm, 3 w, 5%	Ward Leonard 3X10	115-0421
R20	1	Resistor,Fixed,Power,Axial 13 K ohm, 1 w, 5%	Tepro Electric TS1W	115-1309
R21,35	2	Resistor,Fixed,Precision,WW 1.2 K ohm, 1 w, 5%	Tepro Electric TS1W	115-1306
R22,38,41	3	Resistor,Fixed,Precision,WW 510 ohm, 1 w, 1%	Tepro Electric TS1W	115-1466

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

AMPLIFIER BOARD, PCB#1, ASS'Y A1, MODEL KS 60-5 (M) Code 11-1864

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
R23	1	Resistor, Fixed, Molded 1.1 K ohm, 1/2 w, 5%	Allen Bradley EB1125	115-0448
R24	1	Resistor, Fixed, Molded 12 K ohm, 1/2 w, 10%	Allen Bradley EB1231	115-1168
R25	1	Resistor, Fixed, Molded 1 K ohm, 1/2 w, 5%	Allen Bradley EB1021	115-0547
R27	1	Resistor, Fixed, Molded 5.6 K ohm, 1/2 w, 10%	Allen Bradley EB5621	115-1201
R28	1	Resistor, Fixed, Precision, WW 570 ohm, 1 w, 1%	Tepro Electric TS1W	115-1465
R31	1	Resistor, Fixed, Molded 100 ohm, 1/2 w, 5%	Allen Bradley EB1015	115-0341
R32	1	Resistor, Fixed, Molded 1.8 K ohm, 1/2 w, 10%	Allen Bradley EB1821	115-0473
R33	1	Resistor, Fixed, Precision, WW 6.2 K ohm, 1 w, 5%	Tepro Electric TS1W	115-1335
R34	1	Resistor, Fixed, Precision, WW 2.5 K ohm, 1 w, 5%	Tepro Electric TS1W	115-1307
R36	1	Resistor, Fixed, Power, Axial 10 K ohm, 3 w, 5%	Sprague Electric 151E-10K	115-0460
R40	1	Resistor, Variable 150 ohm, 1/2 w, 10%	Bourns 3067P-1-151	115-1534
R42	1	Resistor, Variable 100 ohm, 1/2 w, 10%	Bourns 3067P-1-10-1	115-1434
R44	1	Resistor, Fixed, Molded 300 ohm, 1/2 w, 5%	Allen Bradley EB3015	115-0783
R46	1	Resistor, Fixed, Molded 510 ohm, 1/2 w, 5%	Allen Bradley EB5115	115-0824
R50, 51	2	Resistor, Fixed, Molded 2.2 K ohm, 1/2 w, 10%	Allen Bradley EB2221	115-0466
R54	1	Resistor, Fixed, Molded Glass 51 K ohm, 1/2 w, 5%	Corning Glass C20	115-1455
R55	1	Resistor, Fixed, Precision, WW 1 ohm, 1 w, 1%	Tepro Electric TS1W	115-1361
R57	1	Resistor, Fixed, Molded 330 ohm, 1/2 w, 10%	Allen Bradley EB3311	115-0804
R61	1	Resistor, Fixed, Power, Axial, WW 5 K ohm, 3 w, 5%	Hardwick Hindle 9/16 GA5000 LTC	115-1094
R62	1	Resistor, Fixed, Molded 2 K ohm, 1/2 w, 5%	Allen Bradley EB2025	115-0520

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kepco inc. ® REPLACEMENT PARTS LIST

MAIN CHASSIS, ASS'Y A2, MODEL KS 60-5 (M) Code 6-1164

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
FRONT PANEL ASSEMBLY INCLUDES:				
DS101,102	2	Pilot Light Assembly	Drake Mfg. 7-503	152-0071
F101	1	Fuse, Slo Blo 10 a	Bussman MDA-10	141-0057
F102	1	Fuse, Slo Blo 1 a, 250 v	Bussman MDL-1	141-0047
*M101	1	Meter, Volt 0-60 v	General Electric 8DW91V202AR2	135-0149
*M102	1	Meter, Amp. 0-5 a	General Electric 8DW91A227BT2	135-0171
R101	1	Resistor, Variable, Multiturn 6.5 K ohm	IRC Model 8000	115-1450
R102	1	Resistor, Variable, Multiturn 50 ohm	Bourns 3507-S-319-500	115-1448
S101	1	Switch, Toggle, SPST 15 a, 125 v	Carling Electric AA252-63XKEP2	127-0107

*Metered Models Only.

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kepco inc. ® REPLACEMENT PARTS LIST

MAIN CHASSIS, ASS'Y A2, MODEL KS 60-5 (M) Code 3-365

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
B201	1	Motor	Barber Colman KYAF764-1	148-0006
C201, 203, 204	3	Capacitor, Electrolytic, Can 7900 µf, 120 v	General Electric 43F3251CA3	117-0411
C203	1	Capacitor, Electrolytic, Can 350 µf, 120 v	General Electric 43F3328CA3	117-0406
C205	1	Capacitor, Electrolytic, Can 200 µf, 150 v	General Electric 43F3350CA3	117-0418
C208	1	Capacitor, Ceramic 0.005 µf, 500 v	Sprague Electric 19C242	117-0061
C209, 210	2	Capacitor, Electrolytic, Pigtail 1 K µf, 6 v	Industrial Cond. 1B1382-RM	117-0346
	1	Rectifier Assembly Includes the following:	Kepco Inc.	124-0201
C211	1	Capacitor, Mylar 5 µf, 200 v, 20%	Good All X663F	117-0372
CR201, 202	2	Rectifier, Silicon, Stud Type	Motorola 1N3210	124-0165
CR203, 204	2	Rectifier, Silicon	General Electric C30B	124-0268
CR206, 207	2	Rectifier, Silicon, Pigtail	Semicon Inc. SM-140	124-0028
R216, 217	2	Resistor, Fixed, Molded 220 ohm, 1/2 w, 10%	Allen Bradley EB2211	115-0371

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REPLACEMENT PARTS LIST

MAIN CHASSIS, ASS'Y A2, MODEL KS 60-5 (M) Code 3-365

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
CR205	1	Zener Diode	Hoffman 1N1805	121-0038
R201	1	Resistor, Fixed, Power, Strip 7.5 ohm, 10 w, 5%	Hardwick Hindle BRS-56	115-1425
R202	1	Resistor, Fixed, Power, Strip 30 ohm, 10 w, 5%	Hardwick Hindle	115-1506
R203	1	Resistor, Fixed, Power, Strip 300 ohm, 40 w, 5%	Hardwick Hindle 2BR-37-300	115-1078
R204	1	Resistor, Fixed, Power, Strip 2 K ohm, 10 w, 5%	Hardwick Hindle BRS-56	115-1521
R205	1	Resistor, Fixed, Precision 0.1 ohm, 50 w, 1%	Tepro Electric TM-50M	115-1387
R206, 207	2	Resistor, Fixed, Power, Strip 500 ohm, 40 w, 5%	Ward Leonard 40S500	115-0201
R209	1	Resistor, Variable, Composition 50 K ohm, 2 w, 10%	Allen Bradley JA1L040S503UZ	115-0437
R210	1	Resistor, Fixed, Composition 13 K ohm, 1/2 w, 5%	Corning Glass C20	115-1460
**R211	1	Resistor, Precision 60 K ohm, 5 w, 3%	Tepro Electric TS5W	115-1530
T201	1	Transformer	Kepco Magnetics	100-1378

**Un-Metered Units Only.

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kepco inc. ® REPLACEMENT PARTS LIST

SCR CONTROL BOARD, PCB#2, ASS'Y A3, MODEL KS 60-5 (M) Code 3-365

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
C303,305, 306,314	4	Capacitor,Mylar 0.1 µf, 200 v, 10%	TRW Type X663F	117-0363
C307	1	Capacitor,Mylar 0.4 µf, 200 v, 10%	TRW Type X663F	117-0128
C308	1	Capacitor,Mylar 0.1 µf, 600 v, 20%	TRW Type X663F	117-0316
C310	1	Capacitor,Mylar 0.5 µf, 200 v, 10%	TRW Type X663F	117-0123
C311	1	Capacitor,Mylar 0.05 µf, 200 v, 10%	TRW Type X663F	117-0362
C312	1	Capacitor,Mylar 1 µf, 200 v, 10%	TRW Type X663F	117-0207
CR306	1	Rectifier,Silicon,Pigtail	Semicon Inc. SM-140	124-0028
CR307	1	Zener Diode	Transitron SV125	121-0028
CR308	1	Zener Diode	Motorola 1N3026B	121-0036
CR309	1	Rectifier,Silicon,Pigtail	Semicon Inc. SM-110	124-0133
Q301	1	Transistor,Silicon,NPN	General Electric 2N336A	119-0056
Q302	1	Transistor,Unijunction	General Electric 2N338	119-0048
Q303,304	2	Transistor,Silicon,PNP	Hughes 2N1131A	119-0055
R302	1	Resistor,Fixed,Molded 10 K ohm, 1 w, 10%	Allen Bradley GB1031	115-0040
R303	1	Resistor,Fixed,Molded 8.2 K ohm, 1/2 w, 10%	Allen Bradley EB8221	115-1169
R305	1	Resistor,Fixed,Power,Axial 30 ohm, 3 w, 5%	Ward Leonard 3X30	115-0773
R306	1	Resistor,Fixed,Molded 6.8 K ohm, 1/2 w, 10%	Allen Bradley EB6821	115-0857
R307	1	Resistor,Power,Axial 2 K ohm, 5 w, 5%	Ward Leonard 5X2000	115-0568
R308	1	Resistor,Fixed,Molded 470 ohm, 1/2 w, 10%	Allen Bradley EB4711	115-0608
R309	1	Resistor,Fixed,Molded 330 ohm, 1/2 w, 10%	Allen Bradley EB3311	115-0804

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kepco inc. ® REPLACEMENT PARTS LIST

SCR CONTROL BOARD, PCB#2, ASS'Y A3, MODEL KS 60-5 (M) Code 3-365

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
R310	1	Resistor, Fixed, Molded 3.3 K ohm, 1/2 w, 10%	Allen Bradley EB3321	115-0439
R311	1	Resistor, Variable 5 K ohm, 1/2 w, 10%	Bourns 3067S-1-502	115-1363
R312	1	Resistor, Fixed, Molded 1.2 K ohm, 1/2 w, 5%	Allen Bradley EB1225	115-1167
R313, 314	2	Resistor, Fixed, Molded 10 K ohm, 1/2 w, 10%	Allen Bradley EB1031	115-0489
R318	1	Resistor, Fixed, Molded 10 ohm, 1/2 w, 10%	Allen Bradley EB1001	115-0502
R319	1	Resistor, Fixed, Molded 1 K ohm, 1/2 w, 10%	Allen Bradley EB1021	115-0547
R321	1	Resistor, Fixed, Molded 470 ohm, 1/2 w, 5%	Allen Bradley EB4715	115-0919
R322	1	Resistor, Variable 500 ohm, 1/4 w, 20%	Allen Bradley FR500M	115-1501
R323	1	Resistor, Fixed, Molded 470 ohm, 1/2 w, 5%	Allen Bradley EB4711	115-0608
R324	1	Resistor, Fixed, Molded 68 K ohm, 1/2 w, 5%	Allen Bradley EB6835	115-0273

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REPLACEMENT PARTS LIST

REFERENCE ASS'Y, PCB#3, ASS'Y A5, MODEL KS 60-5 (M) Code 10-2065

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
C501	1	Capacitor, Electrolytic, Pigtail 20 µf, 150 v	General Electric 43F2271AA2	117-0145
C502	1	Capacitor, Electrolytic, Pigtail 1 K µf, 10 v	General Electric 43F2381AA2	117-0176
C503	1	Capacitor, Electrolytic, Pigtail 150 µf, 75 v	General Electric 43F7147AA1	117-0388
C504, 505	2	Capacitor, Electrolytic, Pigtail 22 µf, 25 v, 20%	General Electric 76F02KE220	117-0503
C506	1	Capacitor, Electrolytic, Pigtail 500 µf, 50 v	General Electric 43F2528AA1	117-0221
CR501, 503, 504	3	Rectifier, Silicon, Pigtail	Semicon Inc. SM-140	124-0028
CR502, 505, 506, 508, 509, 510	6	Rectifier, Silicon, Pigtail	Semicon Inc. SM-110	124-0133
CR507	1	Zener Diode	Hoffman 1N1773	121-0012
K501	1	Relay, 3PDT	Omega Electric 200PC3CX	140-0040
R501	1	Resistor, Fixed, Molded 100 K ohm, 1/2 w, 10%	Allen Bradley EB1041	115-0809
R502	1	Resistor, Fixed, Power, Axial 1 K ohm, 5 w, 5%	Ward Leonard 5X1000	115-0512
R503	1	Resistor, Fixed, Power, Axial 2.5 K ohm, 3 w, 5%	Ward Leonard 3X2500	115-0469
R504	1	Resistor, Fixed, Molded 47 ohm, 1/2 w, 10%	Allen Bradley EB4701	115-0718
R505	1	Resistor, Fixed, Power, Axial 2.0 K ohm, 5 w, 5%	Ward Leonard 5X2000	115-0568
T501	1	Transformer, Reference	Kepco Magnetics	100-1543

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PLUG-IN ASSEMBLIES A6 THROUGH A11, MODEL KS 60-5 (M) Code 6-1164

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
A6	1	Driver Assembly Includes the following:	Kepco Inc.	110-0182
C601	1	Capacitor, Mylar 0.2 μf, 200 v	TRW X663F	117-0236
Q601	1	Transistor, PNP	Delco 2N174	119-0016
R601	1	Resistor, Power, Axial, WW 225 ohm, 5 w, 5%	Tepro Electric TS5W	115-1503
A7	1	Driver Assembly Includes the following:	Kepco Inc.	110-0183
Q701	1	Transistor, PNP	Delco 2N174	119-0016
R701	1	Resistor, Fixed, Molded 100 ohm, 1/2 w, 10%	Allen Bradley EB1011	115-0626
R702	1	Resistor, Fixed, Power, Axial 10 K ohm, 3 w, 5%	Sprague Electric 151E-10K	115-0460
A8	1	Pass Assembly Includes the following:	Kepco Inc.	110-0181
Q801	1	Transistor, PNP	Delco 2N174	119-0016
R801	1	Resistor, Fixed, Power, Axial 0.1 ohm, 3 w, 5%	Tepro Electric TS3C	115-0819
R802	1	Resistor, Fixed, Power, Axial 5 K ohm, 5 w, 5%	Ward Leonard 5X5000	115-0232

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REPLACEMENT PARTS LIST

PLUG-IN ASSEMBLIES A6 THROUGH A11, MODEL KS 60-5 (M) Code 6-1164

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
A9	1	Pass Assembly Includes the following:	Kepco Inc.	110-0184
Q901	1	Transistor, PNP	Delco 2N174	119-0016
R901	1	Resistor, Fixed, Power, Axial 0.1 ohm, 3 w, 5%	Tepro Electric TS3C	115-0819
S901	1	Thermostat, N.C.	Chatham Controls DRSCORP73C	127-0093
A10	1	Pass Assembly Includes the following:	Kepco Inc.	110-0180
Q1001	1	Transistor, PNP	Delco 2N174	119-0016
R1001	1	Resistor, Fixed, Power, Axial 0.1 ohm, 3 w, 5%	Tepro Electric TS3C	115-0819
R1002	1	Resistor, Fixed, Power, Axial 250 ohm, 5 w, 5%	Ward Leonard 5X250	115-0402
A11	1	Pass Assembly Includes the following:	Kepco Inc.	110-0177
Q1101	1	Transistor, PNP	Delco 2N174	119-0016
R1101	1	Resistor, Fixed, Power, Axial 0.1 ohm, 3 w, 5%	Tepro Electric TS3C	115-0819

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

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